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MUNICIPAL WASTE DISPOSAL BY SHIPBORNE INCINERATION AND SEA DISPOSAL OF RESIDUES

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Because of improper past disposal of municipal wastes into ocean waters, this study investigated the use of waste incinerator ships. The following points were studied: (1)well-burned residues are harmless to marine species; (2)there will be no concentration or transmission of toxic substances through the marine food chain; (3)floatable residue capable of littering can be eliminated; (4) air pollution will be prevented along coastal areas; (5)residue will not migrate from defined deposition sites. This report represents the investigations of each of these aspects over a 5-year period.

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NOTE: A detailed Table of Contents plus a List of Tables and a List of Figures **precedes** each Section.

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

As part of an effort to solve the problem of solid waste disposal, this study examines the feasibility of waste incinerator ships. This grant, published by the National Environmental Research Center - Cincinnati provides information on methods of ocean disposal and the effects this activity have on the water and air environment.

A. W. Breidenbach, Ph.D.
Director
National Environmental
Research Center - Cincinnati

SUMMARY

It is apparent that there is widespread dissatisfaction with traditional methods of solid waste handling and disposal. They have proven expensive, dangerous to those engaged in their operation, a source of pollution to air, water, and land, and generally offensive to the citizenry. As a consequence, waste disposal facilities almost without exception are unwelcome neighbors and attempts to acquire and utilize new disposal sites are met with intense and, often, politically potent opposition on the part of prospective abutters. Open land areas remote from other activities become increasingly distant from the central city where most waste is generated and different governmental jurisdictions make their acquisition for waste disposal very difficult. Even when the jurisdictional problems of acquiring remote disposal sites can be resolved satisfactorily, the cost of long distance transportation of wastes often makes their utilization uneconomical.

These problems appear to be most acute for the oldest and largest U. S. Cities along the Atlantic coast but, happily, these metropolitan areas have the option of looking seaward for large unoccupied open spaces that are remote from objecting abutters. In former years, this resource was misused by many of these same coastal cities for waste disposal operations. They made a regular practice of dumping raw garbage and trash into coastal waters and this noisome practice resulted in serious ocean and beach pollution. Quite properly, it was prohibited by the Federal Government about 20 years ago.

Current thinking tends to regard each element of the environment as a resource that is most valuable when exploited to the maximum degree compatible with prudent safeguards for human health, well being, and preservation of property. The objective must always be to utilize to the fullest the self-purifying properties of the environment which are enormous when properly understood and managed (1). With these desirable ends firmly in mind, it was proposed a few years ago (2) that waste incinerator ships be constructed to service coastal cities. Under this plan, waste collections would be transported to dockside and transferred to an ocean going incinerator ship. After loading, the vessel would put to sea, burn the wastes, and discharge the residues into deep holes in the ocean floor.

In the light of previous poor experiences with other types of ocean disposal of solid wastes, it is necessary to demonstrate the following critical points if plans of this nature are to be accepted by all interested groups, which include public health officials, conservationists, marine biologists and ecologists, as well as commercial and sports fishermen:

1. The innocuous nature of well-burned residues to marine species on a long and short exposure basis.
2. That there will be no transmission or concentration of toxic heavy metals or other toxic substances through the marine food chain.
3. Floatable residue components capable of littering the ocean surface can be eliminated.

4. A condition of air pollution from this source will be prevented along coastal areas.
5. Ocean bottom littering by migration of residue from designated and defined deposition sites will not occur.
6. The engineering feasibility of ship and waste handling operations, incinerator design, and economic factors.

Investigations of each of these important aspects of shipborne incineration have been conducted for approximately 5 years by a multidisciplinary group of research scientists and engineers and a large body of relevant research information has been assembled

The major portion of the work has been performed by the staff of the Harvard School of Public Health. Supporting studies, particularly with respect to physical oceanography and the biological effects of incineration residues on marine life, have been conducted by the staff of the Graduate School of Oceanography, University of Rhode Island.

Municipal incinerator residues vary greatly in particle size as well as physical and chemical composition in response to the changeable nature of waste collections and the efficiency of the combustion process. As many of our research studies required the use of incinerator residue (most particularly for toxicity studies), a typical residue was sought. Samples were collected from 6 municipal incinerators in the Greater Boston area and analyzed for composition, particle size, and floatable fraction.

In each case, a gross sample of 500-600 lbs. of hot residue was obtained from the discharge end of an incinerator, spread on a clean concrete apron to cool, and sieved through a 1/2 inch screen. The over-sized fraction was separated into (a) cans and other metals, and (b) non-metals. After weighing, the over-sized fraction was discarded. The under 1/2 inch fraction (from 23 to 52% by weight) was mixed and reduced by coning and quartering to a sample of convenient size. The mass median diameter of the under 1/2 inch residues ranged from 1.3 to 3.5 mm as determined by sieve analysis and the size range was very broad. Tin cans represented between 11 and 24% with the total weight of the residues.

One sample of under 1/2 inch residue had 4% combustible content, determined by 24 hour heating at a temperature of 800°C, but the remainder ranged between 13.5 and 27.5% combustible, indicating varying degrees of poor combustion. It was noted that a large fraction of the combustible material consisted of fragments of wood charcoal but in some cases there appeared to be incompletely burned garbage as well. An approximate evaluation of the magnitude of the incompletely reduced garbage fraction was sought by analyzing the crude residues for percentage of ether-soluble fat. These values ranged from approximately 0.1 to 0.3% by weight, indicating that variable amounts of incompletely reduced food waste remained.

In well burned residues, the fraction that was larger than 1/2 inch consisted of items such as metals and glass that are normally non-buoyant in sea water. About 3% of the material between 1/2 inch and 1-mm floated in sea water and this fraction was made up of charcoal and paper fragments that can be destroyed on reburning. The size fraction below 1-mm contained about 0.5% floating particles. Although under 1-mm particles are less easily identifiable because of their small size, they, too, appeared to be largely particles of wood charcoal, paper, and other substances which can be destroyed by reburning. Small, dry, cooled particles of well-fired incinerator residue were found to be extremely difficult to wet and up to 40% by weight resisted wetting when introduced into sea water. However, when dropped into water at incinerator temperatures, there were no wetting difficulties.

Most of the particles greater than 1-mm diameter consisted of fragments of glass, stones, charcoal, and similar items of a non-water-soluble nature. From one to four percent of the material below 1-mm diameter was found to be water soluble and this soluble fraction contained nitrates, ammonia, sulfates, and other components of importance in the nutrition of marine plankton. The heavy metal content of incinerator residues is of special interest because of potential toxicity to marine organisms and the possibility of reaching man in abnormal amounts through concentration in the marine food chain. Cadmium, chromium, cobalt, copper, iron, lead, manganese, nickel, and zinc were determined for the less-than-1/2 inch size fraction of the incinerator residues. The analyses were made in two ways: first, the total content of each metal was determined by acid digestion and second, only the sea water soluble fraction was determined. The average total heavy metal content of 6 samples of Boston municipal incinerator residue collected on different days and extracted by acid digestion was as follows: (3)

Metals	ppm
Fe	40,000
Zn	5,000
Pb	4,000
Cu	1,000
Mn	700
Ni	70
Cr	60
Co	20
Cd	10

Concentrations ranged from 10 ppm for cadmium and 60 ppm for chromium to 40,000 ppm for iron. Lead content averaged 4,000 ppm but varied from 706 to 9,700 ppm in different samples. As would be expected, the percentage of the total metal content that is directly soluble in sea water (i.e., without acid digestion) is generally less than 1% of the acid soluble values and usually below the detection limit. Although not quantitated, the principal solutes in sea water are the alkali metals which evidenced their presence by a rise in pH when the residues were steeped in fresh or sea water.

Bioassays were conducted on a variety of marine species with incinerator residues from the Boston municipal incinerator to make it possible to predict the effects of dumping large amounts of non-floating residue over a long period of time. The experiments included a wide variety of species representing several phyla and utilized the soluble extract from incinerator residues, residues that were stripped of sea water soluble components, and "whole" or unleached residues. Most bioassays were conducted with the latter. Exposure periods ranged from one day (to determine acute toxicity of high residue concentrations) to more than three years (to determine long term effects from prolonged exposure to twice weekly residue additions). Although survival rates of the various marine organisms (compared to appropriate controls) constituted the principal toxicity assay measurement, sub-lethal effects were evaluated by measuring the reactions of treated fish to sound stimuli, by hatching and larval experiments, and by long period growth rates.

Many experiments were conducted with winter flounder (Pseudopleuronectes americanus Walbaum) because this important food fish is a bottom dweller and might be expected to come into intimate contact with incinerator residues discharged into the ocean. It was found that the median tolerance level for both 24-hour and 10-day exposures to under 1/2 inch whole residue particles was in excess of 10% of the weight of sea water. Although conditions of this nature can be created in aquaria, residue concentrations of this magnitude are impossible to attain in the open ocean under any foreseeable circumstances, indicating that incinerator residue on the ocean bottom would have an exceedingly low order of toxicity for this bottom dwelling fish.

When identical experiments were conducted with equal weights of the fraction of the whole residue below 1-mm in size, toxicity increased. It was observed that continuously stirred residues were more toxic than the same sizes and concentrations of residue without mechanical stirring and it was concluded that when rough particles of small size are kept in suspension, they enter the gill structure of the fish and produce mechanical injuries to the gill epithelium which serve as sites for infections. In this connection, it is appropriate to note that naturally-occurring silts can produce measurable toxicity to fish within a few hours when the bottom is stirred vigorously by natural phenomena. Therefore, mechanical injury to the gill structure of fish when confined in waters containing unnaturally high concentrations of suspended particulate matter is not a unique effect of stirred incinerator residue particles.

In this summary of the acute toxicity of incinerator residues for a variety of marine species, it is important to keep in mind that the objective was to determine at what level harmful effects could be induced, no matter how improbable the occurrence of these concentrations might be in nature. Therefore, it is important to place the concentrations at which toxic effects occur in proper perspective with relation to the amounts of residue that might be deposited on small, isolated areas of the ocean bottom. It would require 1,000 tons of residue to be dumped daily for 25 years onto a one square mile, 200 foot deep, ocean disposal site to accumulate, for example, a 1% concentration of residue in the size range that was used for the bioassay experiments. This assumes that the residue remains unchanged; but, of course, natural processes would, with time, act to change many of the products into normal appearing and normal acting bottom silt indistinguishable from the natural bottom environment. Therefore, considerably longer than 25 years would be required, in practice, to build a residue concentration of 1%, if, indeed, it could ever be attained in the ocean. It would be naive to expect that sites used for daily deposition of incinerator residues over long periods of years would remain hospitable to all bottom dwelling marine species (shell fish, worms, etc.) but it can be expected that disposal sites will be selected that are remote from sport and commercial fishing areas in the same manner that explosives, dangerous chemicals, and mud disposal sites are now chosen by the Coast Guard and U. S. Army Engineers and displayed on marine navigation charts of the coastal areas in the vicinity of large cities. Under these circumstances, the net effect on the survival and propogation of marine species will be negligible.

The following results of short period bioassays, among very extensive biological data, may be cited as typical:

1. Quahaug (Mercenaria mercenaria Linnaeus): No mortality occurred when placed in whole residue concentrations up to 10% for 90 days.

2. Common mummichog (Fundulus heteroclitus Linnaeus): No mortality occurred in whole residue concentrations up to 30% for 60 days.
3. Shrimp (Palaemonetes vulgaris Say): High mortalities occurred at whole residue concentrations above 5.6%.
4. Sand shrimp (Crago septemspinosus Say): No significant mortality occurred at whole residue concentrations below 1.8%.
5. Juvenile menhaden (Brevoortia tyrannus Latrobe): High mortalities occurred during the first 24 hours at most concentrations. However, no mortality occurred after the first 24 hours at concentrations up to 10%.
6. Adult lobster (Homarus americanus Milne-Edwards): No mortality at concentrations up to 10% for 10 days.
7. Lobster larvae (Homarus americanus Milne-Edwards): Fourth stage lobster larvae died rapidly in control and treatment tanks. However, no excess mortality due to whole residue concentrations up to 5.6% could be detected.
8. Juvenile millet (Mugil cephalus Linnaeus): No significant mortality in whole residue concentrations below 3.2%.
9. The sea scallop (Placopecten magellanicus Gmelin) was the most sensitive of the species tested and had a 24-hour median tolerance level of greater than 10% concentration for whole ash and for residue extract, and a 10-day median tolerance level of 2.3% and 1.9% concentration for whole ash and extract, respectively. Whether or not the sea scallop is the most sensitive specie is not known as it was not possible to test all species in these tests. Scallops

were subjected to longer term assays of 3 and 4 months duration in 1% residue concentrations. Survival and growth changes for exposed and control animals were indistinguishable, indicating that damage is unlikely outside the boundaries of a designated disposal site.

Twice weekly additions of residue for 37 months to harbor pens containing hard shell clams (Mercenaria mercenaria) showed lower mortality and higher growth rates for residue-treated clams than for untreated controls and more favorable responses from those treated with larger applications of residue. The explanation for better growth and survival of the residue-treated clams is believed to be related to a coarsening of the naturally silty sediment of the habitat and the addition of nutrients from the residue. Long term assays for flounder were conducted for periods up to 7 months. They showed no excess mortality for exposed fish over untreated controls. Fatty acid ratios of treated and controlled fish showed no differences nor was there evidence of concentration of any trace metal from the residue. Similar results regarding non-concentration of heavy metals were observed for all species tested and suggest that this factor is unlikely to cause toxicity to exposed marine species nor is there likely to be significant concentration of these elements in food fish important to man.

The purpose of physical oceanographic studies was to develop criteria for the selection of appropriate sites for disposal of incinerated residues to avoid the spreading of materials from the boundaries of designated disposal areas. Experimental sites were utilized to determine the stability of residues at different water depths. Cans and bottles were chosen to represent the least stable of the residue components, a selection that was made after observing the behavior of many residue materials on the ocean bottom. Large, heavy objects (such as chunks of metal and fused clinkers) fall rapidly through the water, become imbedded in the bottom silt, and remain immovable under all circumstances provided they are deposited beyond the influence of strong tidal flows. Finely divided materials of whatever composition settle to the bottom where they overlay and mix with the natural sediment and, after compaction and weathering, become nearly, if not completely, indistinguishable in appearance and in effect on the environment. Cans and bottles represent an intermediate type of component because they are large enough to experience substantial forces on exposed faces from tidal and bottom currents as well as from transmitted surface wave actions and they approach a condition of neutral buoyancy because of their low weight to volume ratio which is accentuated when sunken containers are partially filled with trapped air. In addition to these characteristics, which make their behavior on the bottom an excellent index of stability for the entire body of residue, they represent items which are especially irritating to commercial fishermen who are concerned about the ability of cans and bottles to foul and cut their nets if they migrate from designated disposal areas.

Direct observations of residue behavior under the influence of ocean currents and surface wave action were made at two locations off the southern shore of Rhode Island. A shallow water site, approximately 50 feet deep and 1.7 miles from shore, was monitored by SCUBA divers whereas a deep water site, approximately 200 feet deep and 18 miles from shore, was observed periodically over a period of several months with the aid of a small research submarine (Perry PB-3 Cubmarine). Visual site surveys were correlated with weather, current, and wave height measurements that were made at each site from instrumented buoy arrays and underwater installations. These observations and measurements were supplemented with periodic general surveys of fish life and epibenthic marine forms to assess the effects of residue dumping.

It was observed in shallow water that when surface wave action was violent, it could be transmitted to the bottom with sufficient energy to produce orbital bottom velocities capable of causing cans to roll back and forth and to rise slightly from the bottom. When this occurred, bottom currents and tidal currents that were otherwise incapable of initiating can movement produced a small but significant net displacement before the can settled to the bottom ready for the cycle to be repeated. Both wave and tidal current effects at the bottom decrease with depth, indicating that residue stability increases as one goes to deeper waters. It is not necessary to go to depths where even the most violent storm will produce absolutely no orbital velocities of sufficient magnitude to move cans because they tend to disintegrate in sea water at a fairly rapid rate. Observations of incinerated cans suspended in sea water indicate that within one year the metal disintegrates into a mass of small, flat, crumbly scale particles that can no longer be distinguished as a can residue. Following a violent autumnal storm, the maximum distance a half gallon can was observed to have moved in 200 foot deep waters was approximately 50 feet from its original deposition site after having remained motionless the entire summer. Waves severe enough to move cans at this depth occur, on the average, from 5 to 15 days per year and, on this basis, a half gallon can could move a maximum of 750 feet per year from the deposition site (assuming that bottom currents are unidirectional). However, before this maximum distance could be reached, the can would have been reduced to unidentifiable scale. For a mile square dumping site, a 750 foot migration distance would be insignificant.

On the basis of these and other observations, it has been concluded that incinerator residues should be deposited in waters at least 200 feet deep to avoid significant migration from the assigned site under the combined effects of wave action plus tidal and bottom currents and that depressions in the ocean floor, where bottom currents are minimal, would be ideal.

Although it might seem natural to assume that large scale dumping of waste materials in a small area of the ocean bottom would produce local destruction of marine life, observations indicate that fish life tends to increase significantly in the vicinity of marked changes in the physical characteristics of the bottom. Fishes and crustacea were markedly attracted to our experimental dump sites. A large mud and sludge dumping site originating from the dredging of Providence harbor (4) was observed to attract exceptionally large numbers of marine species important to man (in spite of the foul nature of the deposits). The beneficial nature of artifical reefs for the attraction, protection, and propagation of lobsters and many species of game fish have been reported by others and on the basis of this evidence it is not impossible (but not yet proven) that large scale dumping of incinerator residues could produce some beneficial effects of significance for commercial and sports fishermen.

Meteorological studies were conducted to evaluate the risk of increased air pollution in coastal urban areas from off-shore waste incineration and to determine safe burning sites for every weather pattern likely to be experienced in an off-shore region.

As atmospheric turbulence is usually less well developed over ocean regions compared to land surfaces, the rates of turbulent mixing and dilution of smoke plumes are lower when overwater travel paths are involved. Our studies provided quantitative estimates of overwater diffusion rates in the atmosphere, with special emphasis upon the steady, on-shore sea breeze phenomenon which occurs frequently during the summer and autumn months. A most significant observation has been the great steadiness of the wind over the ocean, even when wind speed is moderately high. As a result of studies in Massachusetts Bay it appears probable that for any weather pattern at least one satisfactory burning site can be found within a 10 mile run from Boston Harbor that will not produce air pollution on land. Most of the time there will be no restrictions on burning because of weather as soon as the vessel clears the inner harbor area. Meteorological studies indicate that similar conclusions can be expected for other large coastal cities, although they have not been studied in detail.

Climatological studies have an important bearing on operation and planning as there will be days when the weather will be too stormy for burning at sea and provision must be made for adequate waste storage facilities for these periods. The size and seaworthiness of the incinerator vessel will influence the number of days that it will not be possible to burn at sea but, regardless of the type of vessel, there will have to be a decision regarding the action to be taken during severely inclement weather. There appear to be four alternatives: (1) adequate central facilities to store waste collections for the maximum number of consecutive days that the incinerator ship will be unable to leave the dock; (2) storage on-site by the waste producers as now occurs during periods of severe snow-storms, hurricanes, and similar incapacitating natural events; (3) dockside flue gas cleaning equipment and tall stacks which will make it possible for the incinerator ship to burn trash while moored during periods of high winds when atmospheric ventilation rates are at a maximum and air pollution potential is at a minimum; and (4) the use of land burial sites that are reserved for use during emergency periods of this nature. The annual frequency of days unsuitable for sailing a ship having the characteristics of a Liberty Ship was found to be 5, whereas for a towed barge operation, the number of unsuitable days approached 20.

A simulation-type computer program has been developed which makes it possible to compare long term (25 years) costs of alternative disposal systems, including ship incineration, land incineration, and sanitary land filling of raw waste collections. Using current data for the City of Boston, the ship plan comes out as the cheapest because Boston's remaining land for filling and residue disposal has an estimated life of less than 5 years. If political restraints are removed and Boston is permitted to seek extensive land disposal sites at the fringes of the Metroplitan area, the simulation model predicts that a system of intown transfer stations and distant sanitary land filling will give the lowest cost. However, if incineration is to be continued, ship burning with residue disposal at sea compares very favorably with local land incineration and land burial of residues at a distance from the City center. It is interesting to note, in this connection, that the New York City Planning Commission has been studying ship incineration and has come to the conclusion that costs will be only slightly greater than for current disposal practices (5).

Originally, it was believed that a self-propelled incinerator ship (such as a converted Liberty Ship of 10,000 tons, obtainable by state and local governmental agencies at no cost through congressional action) would provide a least-cost design but the U. S. Coast Guard's maintenance requirements for oceangoing, self-propelled vessels and the combined requirements of the Coast Guard and maritime unions for ship manpower are rigid and expensive even though the ship would never sail farther than 20 miles from its dock. As a consequence, a towed incinerator vessel, such as a Liberty Ship hull, has a number of advantages which include elimination of annual dry dockings and elimination of navigation and deck crews. Modern Diesel-powered tug boats are powerful and speedy and require crews of only modest size; thereby greatly reducing manpower costs. The possibility of mooring a non-self-propelled incinerator vessel at a burning site for prolonged periods and ferrying each shift of incinerator crews from land to ship in small high speed boats is attractive from the manpower standpoint but the problems associated with open sea transfer of wastes from a carrier ship or barge to an incinerator vessel are too difficult to make the plan practical at this time.

Ideally, solid waste collections should be consolidated at transfer stations located in the centers of collection districts and the wastes transferred to dockside after midnight in 20-ton trailers that can be separated from their undercarriages and loaded onto the deck of the docked incinerator ship with the same kind of loading equipment that is employed currently for containerized cargo shipments. During bad weather, the transfer vehicles and the transfer station bins could be used for temporary storage. At sea, the waste compaction rams built into the transfer trailers could be used to expel waste into incinerator feed hoppers.

After the engines are removed, a 10,000 ton vessel of Liberty Ship dimensions could accommodate three or four 600 ton/day burning units below decks and it would be possible to coordinate incinerator arrangement with the layout of the transfer vehicles on deck to achieve efficient automatic furnace feeding. One seldom realizes what a small percentage of the space in a modern municipal incinerator facility is occupied by the burning units. When truck ramps, unloading facilities, flue gas cleaning systems, and other necessary accessories of a land-based incinerator are eliminated (because they are not needed on a shipborne unit) substantial space economies, as well as capital cost savings, are achieved. A special feature of a shipborne incinerator would be a sea water quench tank at the discharge end into which hot residue would drop. Objects that sank would be discharged to the ocean for final disposal. Floating objects would be skimmed, crushed (to break bottles and flatten cans), dewatered, and recharged to the incinerator to complete combustion of charcoal fragments and similar items.

Studies indicate that manpower requirements will be a major cost item in the operation of a sea-borne incinerator, even with a towed incinerator vessel. Recent developments in on-line computer operation of chemical and petro-chemical manufacturing plants and electrical generating stations suggest the application of this concept to the operation of an incinerator with a minimum number of men. It would be possible to place incinerators on unmanned towed vessels or barges and the associated automatic control systems on the tow vessel. Instrumentation would necessarily include remote-control consoles, closed circuit television monitoring of combustion zones, remote sensing of incinerator temperatures, air flow rates, burning rates, etc. With computer monitoring and control, the frequency of charging and amount of material in the charge to the incinerator, the amount and distribution of combustion air, and retention time in the burning chamber can be varied to give optimum service. Variables to be measured during the incineration process (for use by a computer in determining feed rate, amount of combustion air, and furnace retention time) include the following: (1) stack emissions; (2) temperature in the burning chamber; (3) flue gas temperature; (4) flue gas volume; (5) total hydrocarbons (a measure of combustion efficiency); (6) CO_2 in flue gas(as it relates to stoichiometric air quantity); (7) moisture content of the charge; (8) moisture content of the flue gas. The final step would be to develop a program for the computer which would compute the necessary variables and direct the process control.

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SOLID WASTE MANAGEMENT

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SECTION 1

SOLID WASTE MANAGEMENT

Melvin W. First

A. Environmental Protection and Utilization

Although current interest in and concern for environmental conservation has sensitized many well-meaning individuals to the point where they object instinctively to any proposal which seeks to utilize one or another segment of the environment for waste disposal purposes, it is essential that each proposal be examined by competent scientists and engineers and judged solely on its merits with proper regard for environmental effects, including the aesthetic, and with a careful assessment of the penalties associated with employing alternate sectors of an environment. Ultimately, all waste products must be returned to the environment (to the atmosphere as gases and vapors, to water bodies as liquids and solids, and into the ground) for there is no other place on earth to put them. Recycling of materials will reduce the amounts of waste that must be deposited in one or another part of the environment, but some wastes cannot be recycled under any foreseeable circumstances and even in the recycling process itself, new waste products are generated that must be released to the environment. Under these circumstances, the entire environment must be studied bit by bit and determinations made regarding the amounts and types of waste which may be released into each segment at each location in a safe and aesthetically pleasing manner. This concern for environmental purity extends to the open seas as well.

It seems clear that for the foreseeable future all but a small fraction of the total quantity of solid wastes will be returned to the environment as a means of final disposal. The current tendency to regard each element of the environment as a resource(1) makes it very clear that each becomes most valuable when exploited to the maximum degree compatible with prudent safeguards for human health, well-being and preservation of property. A distinction must therefore be made between contamination of the environment - that is, addition of foreign substances - and pollution - that is, accumulation of contaminants to the point where undesirable effects begin to occur. It is naive to maintain that nothing whatsoever can be added to the environment, for even if it became technically possible to achieve such an ideal, the human and material resources that would have to be committed to this single purpose would be so great that the quality of daily life would be substantially impoverished. Instead, the objective should be to utilize to the fullest the self-purifying properties of the environment, which are enormous when properly understood and managed. In Los Angeles County, for example, all solid-waste collections are used for landfill to transform steep, dry hills and canyons into public parks and golf courses. Most citizens appear well pleased with this decision, although a few express a preference for preservation of the waste lands. Similar considerations and differences of opinion apply to the management of tidal flats. Even staunch conservationists may concede, in good conscience, that not every single acre of tide land is best utilized by being left alone. As poorly located and badly polluted tide lands can be drained, filled and utilized for many good purposes, so, in like manner, can new tidal lands be created in ideal locations to fill needs not now satisfied by natural geologic processes.

It is never possible to predict with certainty the exact effects of large-scale disposal efforts from small-scale pilot and theoretical studies. Therefore, when indications are uniformly favorable, large-scale demonstrations, for extended periods must follow if proper evaluations are to be made. This does not mean that the areas to be used for these large-scale experiments should be allowed to degrade to the point of serious damage. Rather, they should be monitored on a continuous and adequate basis so that incipient damage to the environment can be detected and protective measures employed in an orderly and timely way.

B. The Solid Waste Problem

Solid wastes, often called refuse, include a wide variety of discarded, and generally useless, materials resulting from normal community activities. Garbage and rubbish from households, institutions and commercial establishments comprise the largest fraction of municipal waste collections, but bulky objects, such as stoves and refrigerators and, especially, abandoned automobiles, represent more difficult municipal collection and disposal problems. Industrial refuse from factories, power plants and food-processing plants may contain waste materials not usually found in municipal collections, but more often the difference is quantitative rather than qualitative since industrial processes, by their very nature, generate large amounts of one, or a few, kinds of waste products. By contrast, ordinary municipal collections tend to be extremely diverse.

Prosperity has increased per capita waste production enormously. Modern packaging practices, a spate of periodical literature, almost instant obsolescence of an endless variety of material acquisitions and the enormous growth of industry have combined to increase the daily per capita production of solid wastes in the United States from 2.7 pounds in 1920 to 5.0 pounds in 1970. Similar increases are now occurring in Western Europe. The present trend is equivalent to an annual increase of 25 pounds of waste per capita. Paper consumption alone increased 16.6 per cent during the same interval(2). Even more impressive is a figure of 86,000,000,000 pounds for the total paper and paper-board products consumed during 1963(3).

At a National Conference on the Use and Disposal of Single-Use Items in Health Care Facilities*, it was pointed out that some hospitals already generate up to 20 lbs. of solid waste per patient per day and that when the concept of single use disposal items is extended to include all bed linens, food service, uniforms, and everything else to which it may be applied, hospitals can be expected to generate 50 lbs. of solid waste per patient per day. Admittedly, the hospital is a special case and, moreover, it does not generate a significant fraction of the total solid wastes produced in the community, but it has significance as a portend that total acceptance of single-use disposable items by institutions may soon be followed by enthusiastic general public acceptance, as well. Should this occur, we will find that current planning based on generally accepted projections of future waste production will prove to be grossly inadequate.

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*National Science Foundation, Ann Arbor, Michigan, December 4-5, 1968.

Effective research and development programs for solid-waste handling were virtually nonexistent up to five or ten years ago, and the national annual investment in this activity was less than $300,000 as recently as 7 years ago,in spite of the fact that "Americans living in cities pay each year roughly $3-billion for the collection, transportation, processing and the disposal of solid wastes."(4) The truth of the matter is that research on solid-waste technology has never been a "respectable" activity at universities, technical schools and research foundations although, fortunately, this attitude is undergoing rapid alteration. The penalty for this niggardliness and lack of vision is the current dependence on solid-waste handling methods that are largely obsolescent (when not totally obsolete), inadequate for coping with the quantities of material that will be generated soon, and unsuitable for the rapid and safe disposal of many new materials rapidly coming into common use. Examples of substances in this category are plastic products that are fire resistant and proof against microbiologic and chemical disintegration and aluminum, which, unlike iron and steel, resists rusting and disintegration for very long periods, even when buried in the ground or under water.

It has been recognized, belatedly, that although solid wastes may rate low on a scale of sources of transmissible disease, improper disposal practices can cause serious air, water and land pollution problems of a noninfectious nature. Air pollution problems associated with burning open dumps, poorly constructed and operated incinerators and a variety of salvage operations, ranging from recovery of lead and copper from old electric cables to production of edible and nonedible substances from rendering plants, have become increasingly grave as the volume of wastes and the pressure on the self-cleansing properties of the air environment have increased simultaneously. It is only now, however, that the potential for ground water and surface water pollution associated with leaching of undesirable products from raw or improperly incinerated wastes spread in or on unsuitable ground is beginning to be recognized. Ground pollution occurs when waste-disposal practices place restrictions on the subsequent use of the disposal site. When buildings are erected on old landfills, for example, care must be taken to prevent migration of toxic and explosive gases from the subterranian fill to the interior of the buildings.(5)

Recognition of a worsening situation regarding the level of technology associated with solid-waste collection and disposal practices and an awareness that it is no longer possible in a crowded urban society to treat the 3 broad classifications of pollution (air, water, and land) separately(6) have directed advanced thinking along channels that can be most accurately labeled "solid waste management." The intention is to provide the widest possible scope for cooperative studies of basic interdisciplinery solid-waste problems by urban planners, social scientists, sanitary engineers and public works specialists. In addition, the methods of operations research and high-speed computation are being explored to determine what assistance they can provide to researchers, planners and managers of solid-waste collection and disposal systems.

All procedures for solving solid-waste problems involve the use of one or more of these 3 basic methods: reduction of waste production; reclamation, utilization and recycling of waste products; and returning the wastes to the environment via land, air or water. There seems to be little quarrel with the first 2 proposals, and, indeed, conservationists have been advocating them for many years, but major problems arise in attempting to put them into practice. For example, complex product distribution and sales mechanisms favor the extravagent use of packaging materials for preservation and selling appeal. In many cases, the cost of packaging is a small proportion of the total price, and this is more than compensated for by a reduction in spoilage, breakage, soiling and other losses. It is difficult to foresee any factor in the immediate future that is likely to reverse this trend. Similar considerations apply to all classes of reading matter, and this type of consumption is not likely to call for curtailment of an increasingly literate society. Modern manufactering technics have, in part, reached their present advanced state by the application of automatic, continuous processing machinery. Because close quality control of mass-produced items calls for an endless supply of very uniform raw materials, the use of heterogeneous scrap materials introduces characteristic excess costs that exceed savings in raw materials. The successes of on-line computer-operated refineries and chemical plants illustrate clearly the advantages of continuous large-scale production processes that utilize uniform product inputs and indicate the poor prospects that heterogeneous scrap materials have now and will continue to experience in the raw-materials markets of the future. As a consequence, only one third of the 86,000,000,000 pounds of paper products reaching the United States market annually is salvaged to make new items; 48,000,000,000 cans and 26,000,000,000 bottles are produced annually and virtually all are discarded promptly; 8,000,000,000 pounds of new plastics are produced annually and only 10 per cent is recovered(7). Most of the small percentage of useful materials now recovered for reuse comes from manufacturing processes producing scrap that is clean, of identifiable composition and in large quantities, making it unusually valuable for reprocessing. Almost none of the same products are salvaged after they find their way into municipal or private refuse collections. Operation of a free commodity market in the United States means that, each year, the metals in 48,000,000,000 cans will be returned to the ground at widely dispersed locations because it is now cheaper to mine concentrated ores and produce new metals than to gather together and refine for reuse an equivalent weight of used containers.

Incineration reduces refuse to between one fifth and one tenth its original volume and thereby decreases many times the land area required for final disposal. This means that during the combustion process, 80 to 90 per cent of the volume (50 to 75 per cent by weight) is converted to gaseous products that are discharged to the air environment. When incineration is complete, well over 99 per cent of the gases formed by combustion are carbon dioxide and water vapor. These 2 compounds are found in the normal atmosphere in abundance and are not usually considered to be pollutants although there is considerable current interest in the long-term (one hundred to three hundred years) climatologic effects that may result from an increase in the carbon dioxide content of the atmosphere.

The small percentage of combustion products emitted to the atmosphere from waste incineration that is not carbon dioxide or water vapor consists of particulate matter (soot, smoke and gas-entrained solid residues), organic gases (hydrocarbons or aldehydes) and inorganic gases (sulfur dioxide, hydrogen chloride or oxides of nitrogen). These are all recognized as air pollutants. Under ideal operating conditions, a modern high-temperature municipal-waste incinerator totally destroys all organic matter, and the emissions that are of special interest because of their effect on the air environment will be inorganic - principally particles of solid residue, oxides of sulfur and nitrogen and hydrogen chloride.

Although a reduction in volume of four fifths to nine tenths may be achieved by incineration, solid wastes include many items that are incombustible (such as old refrigerators and junk automobiles) and others that, though combustible, are nonincinerable in existing incinerators (such as tree stumps and urban-renewal demolition wastes).

Figures from Los Angeles County(8) show that 36 per cent of their solid wastes are nonincinerable or noncombustible. When the residue from the incineration of the remainder is added, the total amount of raw waste that must be disposed of in the ground, even when modern incineration plants are employed, is slightly greater than 50 per cent by weight. Because household and commercial refuse contains large amounts of bulky paper products that are almost totally consumed by incineration, the reduction in bulk is more important than residual weight when the effect of incineration on the life of a sanitary landfill site is assessed.

C. Origin of the Ship Incinerator Program

For more than thirty years, the Harvard School of Public Health has been concerned with study and control of environmental hazards. Because of this interest, in 1962, Boston's Mayor requested the President of Harvard to provide some guidance to the Public Works Commissioner who was seeking solutions to both short and long range problems associated with solid waste disposal. A short range answer was needed because of recently authorized state regulations against burning in open dumps.

Boston's problem became acute because of the abrupt closing of some dump facilities and extensive urban renewal projects which generated large amounts of demolition wastes. In addition, the State Department of Health, in order to abate air pollution, prohibited open burning in dumps throughout the commonwealth, as previously noted.

After analyzing the problem in some detail, it became apparent that in the interests of efficiency and sound management, the solid waste disposal problem and its associated air pollution control should be handled on a metropolitan basis, and the city of Boston, with roughly 40% of the metropolitan area population, represented only one of a large group of related communities that needed satisfactory waste disposal facilities for now and in the future.

Because of our research in the control of air pollution from incineration processes as well as contacts with the problem of radioactive waste disposal at sea, and because Boston is a coastal city, we gave some thought to sea disposal possibilities. We had already investigated the potential use of land-operated mobile incinerators. The idea that evolved was to select and locate reasonably well designed incinerators (of a type used in stationary facilities) on available ship hulls such as the World War II Liberty ships (7,000 to 10,000 tons displacement). The many potential advantages of this concept became apparent since it would not require land for dumping of residue, would not need air cleaning equipment or tall stacks, and could handle many kinds of non-combustible debris. The readily apparent disadvantages, such as contamination of the ocean and shore, interference with navigation, possible higher operating cost, crew costs and some limitations because of adverse weather conditions, also occurred to us.

We decided to evaluate how feasible it would be from engineering considerations to carry out incineration on shipboard. It appeared possible to discharge the residue so it would become well wetted below the surface of the sea at extended distances (20 miles or more) from the harbor and shore.

The incinerator ship concept of solid waste disposal, on the basis of preliminary studies, appeared to possess unique advantages for coastal urban areas. Reducing wastes to non-combustible,non-floating residues eliminates the unsanitary and unsightly conditions which existed formerly when raw refuse was dumped at sea. The use of high temperature multi-chambered incinerators on shipboard assures good combustion conditions and the minimum emission of air pollutants; as opposed to many recent proposals to burn refuse at sea in sand-covered steel barges (in effect, open dump burning off-shore). A self-propelled, manned incinerator ship or a towed vessel has the capability of altering its course and position to compensate for wind and weather patterns that are unfavorable for good atmospheric dispersion whereas unmanned, moored barges, once ignited, burn and smoke regardless of weather and wind changes until the charge is finally consumed.

While it is recognized that incinerator ships do not represent a disposal method that can be applied universally, it is applicable, in part at least, to the large fraction of our population that lives adjacent to coastal areas. As these coastal communities, which include most of our oldest cities, are intensively built up (especially so in the areas closest to the water) large land areas suitable for land-fills and incinerator sites are simply no longer available; or such land areas can and should be put to more productive use.

Our preliminary studies of this concept were, in part, aided by air pollution training grant funds and, in part, by Program Project Grant Funds under the control of the School of Public Health. Starting in March, 1965, substantial research grant funds (5 R01 E7 00735-02) were made available through the U.S. Public Health Service, Bureau of State Services, Division of Engineering and Food Protection, Department of Health, Education and Welfare, to carry out this program on an expanded basis. From March, 1966 through June, 1969, grant funding was through the newly established Office of Solid Wastes (8 R01-SW-00044-02) and later through the Solid Waste Management Program of the National Center for Urban and Industrial Health, Consumer Protection and Environmental Health Services (5 R01 UI 00557-03/04).

D. Marine Disposal of Solid Wastes

Sea disposal is not a new concept; solid wastes have been transported by tug and barge and disposed of in the deep sea for many decades. These wastes include dredging spoils, refuse, construction and demolition debris, waste oil, industrial chemicals and sludges, as well as sewage sludge and other materials. A recent study supported by the Solid Waste Management Office, U.S. Environmental Protection Agency(9) has summarized information on ocean disposal of barge-delivered wastes from U.S. cities. The report points out that 62 million tons of wastes were disposed of in the ocean during 1968 at an estimated cost of $37 million. Although harbor dredging spoil accounted for almost 85% of the total tonnage, substantial quantities of refuse, garbage, construction and demolition wastes, and industrial wastes were included in the remainder. The environmental consequences of these disposal practices are largely unknown. A study of a dredge spoil disposal site off Narragansett Bay(10) failed to show direct adverse effects to marine resources of economic importance although some marine organisms were probably destroyed in the localized dumping area. On the other hand, the deposited material appeared to be a positive attraction to fish of many types that found the newly created mud windrows an unoccupied habitat of some attraction. This is the basis for interest in the construction of artificial reefs with waste materials; i.e., the creation of new, and favorable, habitats for commercial and sport fish of all types. In this endeavor, also, little is known about broad ecological effects other than that there is likely to be an immediate attraction for certain marine species. Not all artificial reef construction projects have been successful, largely because of the difficulty associated with keeping the reef intact under the influences of corrosion, erosion, and the hydrodynamic forces generated during violent storms.(11)

A number of attempts have been made to establish artificial reefs for fish breeding by dumping auto body shells in a consistent pattern in relatively shallow waters. Studies indicate that increased fish production results but the bodies gradually disintegrate and when the artificial reefs have been created near shore, metal fragments honed to a razor's edge by the action of waves and sand, wash up on the bathing beaches. Discarded rubber tires, suitably tied together and anchored, have also been used for artificial reef building but selection of the materials capable of withstanding corrosion and erosion has been difficult. Dumping of non-floating, non-polluting bulky wastes beyond the continental shelf has no advantages over disposal 10-20 miles offshore in reserved areas when water depth is adequate (200 feet) and there is an absence of tidal and other currents strong enough to disturb the material on the bottom. Current policies which emphasize recovery and recycling of metals have reduced interest in ocean dumping of discarded autos, refrigerators, etc., but there may remain a need to maintain existing ocean disposal sites for plaster, brick, stone, and similar non-floating demolition and construction wastes in close proximity to densely populated coastal cities undergoing continuous urban renewal. Bulky wastes for disposal in the ocean are usually transported to the disposal site in large bottom-opening (hopper) barges which may be self-propelled or towed. Much interest has been generated in recent years over the possibility of using compressed and stabilized bales of solid wastes and garbage as reef material but little has been accomplished as yet toward solving the problems of physical stability of the bales on the ocean bottom over long time periods and the chemical and biological stability of the baled wastes.

Ocean disposal of coal-fired power station ash has been investigated in New South Wales (12) and in Britain over the past decade but it is not known how extensively such dumping is being carried out, if at all, at the present time.

An objective cited in the Report of the Panel on Oceanography, President's Science Advisory Committee, entitled, Effective Use of the Sea,(13) includes the following, "The ultimate objective of the National ocean program [is] effective use of the sea by man for all purposes currently considered for the terrestrial environment" and one of the specific goals cited is "Undertaking measures required for full exploitation of resources represented by, in and under the sea." The goals of the Panel on Oceanography appeared to encompass, or, at least, not to bar the use of the oceans for waste disposal provided no significant short term damage occurs, and provided long term damage appears to be highly improbable. Indeed, the possibilities of fertilizing the oceans by some types of waste disposal practices have been recognized by many investigators. However, in 1970, a report on ocean dumping by the Council on Environmental Quality(14) has tended to discourage continuation of the practice of ocean disposal, although not completely prohibiting it, since, as was stated, "it is not a serious, nationwide problem now." Nevertheless, this position statement has tended to bring to a halt all but the very smallest field investigations of ecological and other effects from items deposited in the oceans.

E. Research Objectives

This research program has been concerned with an investigation of the scientific, technical, and ecological aspects of ocean burning of municipal solid wastes, including demolition materials, and disposal of the residues at sea. The specific areas of interest include the following: (1) Chemical and biological analyses of typical incinerator residues (collected from a number of modern land-based municipal units) to determine the composition and effect of ash on marine life. Specific toxicants have been sought, as well as the occurence of beneficial substances. For example, typical municipal incinerator residues contain water soluble phosphate and nitrate ions as well as less soluble phosphate compounds. As a phosphate deficiency is believed to be one of the principal limiting factors in the propagation of marine life, the addition of phosphate to the water might have a powerful fertilizing effect on the oceans in the vicinity of the burning grounds.

(2) Effects of deposition and distribution on the ocean floor of daily additions of 500 tons or more of incinerator residue released at the surface over a relatively restricted (1-2 square miles) dumping area. A knowledge of how ocean currents and other factors affect residue movements makes it possible to estimate the effects on marine life; especially on species that normally dwell at or near the bottom.

(3) An ecological study of off-shore areas likely to be selected as suitable burning and dumping grounds and to deduce the effects on marine life of continuous ship-borne incinerator operations.

(4) Meteorological studies of ocean weather regimes in the vicinity of coastal areas to determine diffusion patterns that may be experienced by incinerator ship effluents at different seasons and at various times of the day. A determination of the intensity and distance from shore of the typical summer on-shore and off-shore breezes, and their diurnal variations, is of special importance for establishing safe areas for burning and for the guidance of ship movements. Although wind regimes over water, in the vicinity of land, were known in a general way, detailed studies in relation to the diffusion of stack discharges were lacking.

(5) Investigations of the buoyancy characteristics of incinerator residues and methods of discharging to prevent floating residues.

(6) Use of methods of operations research and high speed computers (a) to optimize collection networks oriented toward waterfront collection routes (b) to locate and schedule mechanized operations of both land and dockside transfer and loading stations and (c) to optimize ship schedules with respect to the distribution of loading and burning times, load size, crew shifts, etc.

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SECTION 2

ENGINEERING FEASIBILITY

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SECTION 2

ENGINEERING FEASIBILITY

Melvin W. First

A. INTRODUCTION

The concept of disposing of solid wastes by transporting them to dockside in pickup and transfer vehicles, loading the material onto specially designed incinerator ships, burning at sea, and disposing of the residues (plus non-combustible bulky items) in designated areas of the ocean bottom was considered sufficiently novel to make it advisable to utilize conventional equipment throughout except when no suitable item was available commercially. This has the disadvantage of eliminating innovative ideas as well as efficiencies inherent in specially designed vessels, burning grates, etc. The advantages are economy, the opportunity to place the new technology into prompt practice, and an ability to make better cost estimates. The latter reasoning has prevailed. Consequently, preliminary engineering planning has been concerned with adapting existing vessels, incinerators, and mechanical handling equipment to the special requirements of an incinerator ship. For example, the capabilities of Liberty ships were evaluated with the aid of plans supplied by the U.S. Maritime Administration. It was found that the decks and cargo spaces provide adequate room for raw waste storage bins and three rotary type incinerators, each having a daily capacity of 600 tons, for a ship's total of 1800 tons per 24 hour day. The removal of most of the oil tanks (required only for overseas crossings) yielded additional cargo space for waste storage to give a total well over two thousand tons.

The sea-going incinerator approach seems to have application for many coastal cities and towns as well as for Great Lakes communities. It provides a means whereby several communities can have an incinerator not located within their confines which has the capability of carrying waste to a remote location, burning it, and discharging the residue in a manner which will not return it to the community or produce shore or beach pollution. Further, a ship provides a vehicle for carrying large objects, i.e., bulky wastes such as abandoned automobiles, for sea disposal at the same locations.

A preliminary evaluation showed that a single ship could handle one half of Boston's waste (the other half is now incinerated at a conventional incinerator) plus that of several communities to the north, e.g., Beverly and Lynn, and to the south, e.g., Quincy and Braintree. Suitable harbor and dockside facilities are available and these are capable of providing terminal locations for waste collection trucks as well. One operating plan provides for waste to be loaded on board during the daily eight hour waste collection period (and perhaps even incinerating at low burning rates at dockside) after which the ship would proceed to sea. Burning would begin as soon as the ship was three to four miles from the dock and continue until the ship had reached a U.S. Coast Guard-designated official burning and disposal ground ten to twenty miles offshore where the ship would discharge the residue as it was burned after slurrying it with sea water. It was anticipated that the slurried ash would settle readily into the depths after floating material had been skimmed from the surface of the slurry tank. A typical one mile square depression in the ocean floor was calculated to be able to handle the incinerated waste from a thousand ton per day incinerator for the next 250 years without creating problems.

An alternative operating plan calls for storing waste collections in silos at dockside during the daily collection period and transferring the entire load to a ship in a short period of time. This would permit the ship to spend more hours at sea and would facilitate rapid loading at several ports in Massachusetts Bay.

B. SHIP INCINERATOR COSTS

In 1963, preliminary estimates were made of ship incinerator costs and these were compared with then-current costs of (1) a modern, land-based incinerator and (2) incineration in a sanitary landfill located at four graduated distances from the center of the metropolitan core area in which a major fraction of the wastes were generated. This is believed to be a reasonable approach to cost comparisons because, as land available for filling becomes more and more remote from the core city, the total cost of sanitary landfill disposal is closely related to the haul distance between pickup and disposal sites Estimation of landfill costs reflect Los Angeles County's experience as reported by Bowerman et.al.(1) and include the economies achievable by the use of local transfer stations and 20-ton tractors to transport consolidated wastes to remote landfill sites. Land-based incinerator costs reflect current records of Boston's modern central incinerator which handles approximately one-half of Boston's total waste collections. All of the cost figures are summarized in Table 2-1 where it may be seen that the estimated per-ton disposal cost for a ship incinerator is less than the cost of disposal in a new land-based incinerator of equal capacity located near the center of the collection district. The relatively low cost of ship incineration reflects two special conditions: (1) Boston already owns functional dock sites for waste transfer from shore to ship that were formerly used for barging raw garbage to sea. (2) At the time these cost estimates were prepared, there were surplus Liberty ships "in mothballs" that could be transferred by an act of Congress to a public agency, such as a city or state, for a nominal payment. It is obvious that substantial ship modifications are required to convert a Liberty ship into an incinerator ship, but acquisition of a sea worthy vessel of this size would substantially reduce the final cost relative to building an entirely new ship because of the salvage value of hull, personnel quarters, cargo handling equipment, propulsion equipment, plus other important items.

It is interesting to note in Table 2-1 the cost dependence of sanitary landfill disposal on haulage distance and the use or non-use of transfer stations for long hauls. It is evident

TABLE 2-1

Comparative System Costs for Transportation and Disposal*
($ per Ton of Refuse)

Cost Item	Sanitary Landfill in the Metro. Area		Sanitary Landfill Outside Metro. Area				Second Boston Incinerator	Mobile Ship Incinerator
Distance to Site	8 miles	13 miles	20 miles		30 miles			
Truck Size	4 ton	4 ton	4 ton	20 ton	4 ton	20 ton		
Transportation	2.55	4.05	6.15	2.20	9.15	3.30	1.05	1.05
Transfer Station	- --	-	-	0.35	-	0.35	-	0.50
Disposal Cost	1.00	1.00	1.00	1.00	1.00	1.00	4.00	2.90
Total	3.55	5.05	7.15	3.55	10.15	4.65	5.05	4.45

* Pick-up costs, the same for all systems, are omitted.

from the table that the cost of landfill disposal is significantly less than incineration only when landfill sites are available close to the pickup areas.

An engineering feasibility and cost study of ship incineration was conducted for the City of New York Planning Commission in 1968(2). It drew heavily on the data accumulated in this study and concluded that "waterborne incineration may provide answers to some of the refuse disposal problems of the City." As New York City also owns several dockside facilities suitable for waste transfer activities from shore to ship, cost comparisons between Boston and New York City for ship incineration are based on closely similar requirements. In addition, inquiry to the New York office of the U.S. Corps of Engineers in 1968 revealed that "the Corps would have no objections to dumping of non-combustible incinerator residue in the waters outside the New York harbor provided that no flotables resulted from the operation, that the dumping would take place in at least 60 feet of water and clear of shipping lanes, and that the material dumped would not be considered objectionable by public health agencies generally and the Federal Water Pollution Control Administration particularly."(2)

To determine the distance from shore which would be adequate to insure against polluting the air over land, reference was made to a 1965 report by the N.Y.C. Department of Sanitation entitled, "Survey, Study and Report on the Disposal of Oversized Burnable Waste."(3) Referring to the offshore distance for barge burning of oversized waste, the report contained the following: "It has generally been agreed by the New York Air Pollution Control Board that 5 miles will suffice during favorable weather conditions (offshore winds) and 10 miles would be satisfactory during inclement weather." For purposes of the N.Y.C. study, it was assumed that burning occurred 10 miles offshore.

An examination of the U.S. Department of Commerce Coast and Geodetic Survey Chart #1215 revealed that dumping spaces which met the U.S. Corps of Engineers physical limitations and the 10 mile offshore air pollution limits exist between the Barnegat to Ambrose sea lane and the Ambrose to Nantucket sea lane. These spaces start at approximately 18 miles from the Verrazano Narrows Bridge at depths of approximately 80 feet and continue to drop off to depths of 100 feet and more within less than 10 miles. It is apparent that incineration and residue disposal could take place between the shipping lanes referred to without causing nuisance or pollution problems, and the locations suitable for this operation are approximately 18 miles from the Verrazano Narrows Bridge.

For the New York City study, several methods of ship incinerator operation were examined for comparative costs:

(1) For the 24-hour cycle, all refuse would be loaded on board during the normal 8 hour daily collection period and burned at sea during another 8 hour period. This schedule would allow eight hours for loading, eight hours for sailing,

and eight hours for incineration each day. The furnace capacity would have to be capable of burning a full day's collections in eight hours. Based upon present incineration practice in the United States, the largest furnace which should be considered for this service is 500-600 tons in 24 hours. If the furnace capacity is 500 tons/day, a collection system load of 1000 tons in 24 hours will require six 500 ton/day furnaces when burning takes place only 8 hours out of 24.

(2) For a 48-hour cycle, all refuse received during the two day period would be stored temporarily on land and then loaded into a vessel in eight hours. This would permit 32 hours of burning out of each two days and only three 500 ton/day furnaces would be required for a 1000 ton per day collection system.

(3) For a 72-hour cycle, all refuse received during the three day period would be stored temporarily on land and then loaded into a vessel in eight hours. This schedule would permit 56 hours of burning out of each three days and only two and a half 500 ton/day furnaces would be required for a 1000 ton per day collection system.

Considering the cost of incinerator furnace construction and operation, a 48- or 72-hour cycle was considered more economical than the 24-hour cycle. Therefore, preliminary designs were based upon 48- and 72-hour cycles and costs were estimated. Another N.Y.C. cost study was based upon the use of a converted Liberty Ship, as was the Boston study.

Three methods of receiving, storing, and charging refuse were examined: (1) Using the hold of the ship as a storage bin for refuse as received and the use of a clam shell traveling crane for feeding the furnace. (2) Grinding and blowing refuse into the hold of the ship and then using a pneumatic suction system for charging refuse into the furnace. (3) Storing refuse in containers using compactors and placing the containers into a conveyance system in the hold of the ship which would permit them to be moved to the furnaces for unloading.

Of the three methods examined, the one that appeared most suitable was the container system. Ships designed to handle and stow containers are in common usage as are compaction container refuse transfer stations. In addition to the proven aspects of the container system, this design permitted considerable flexibility in land-based storage and handling as station capacities can be varied by adding or subtracting containers, and refuse transfer stations, using truck tractor trailers, can be integrated into the system.

Cost estimates applicable to New York City were developed for each of the three systems using 1968 shipbuilding and land-based structure cost information, reasonable capitalization estimates and interest rates, and labor rates for seamen and sanitation employees. Total costs were then reduced to unit cost per ton so that the three ship systems could be compared with each other and to alternate systems in use or under consideration.

The results of the New York City cost study are summarized in Table 2-2(2). It shows that a 3-day ship cycle using a specially constructed incinerator ship results in the highest total annual amortization plus operating cost but the lowest unit cost ($9.20/ton) because a specially designed vessel operating on this schedule is capable of incinerating the largest tonnage of waste. By contrast, a converted Liberty Ship has the lowest annual cost but the highest unit cost because it is poorly adapted to carrying a large number of 8' x 8' x 38' packer-containers, the selected method of loading the vessels.

From Tables 2-1 and 2-2, it may be seen that the lowest New York City estimate is approximately double the Boston estimate. This may be partially accounted for by the general increase in the cost of materials and wages between 1963 and 1968 and by the generally higher wages of New York City employees. Taking these factors into account, as well as the somewhat inexact methods that were used to make both sets of cost estimates, the results are remarkably close. The greater difference between the two Liberty Ship cost estimates is related to the use of waste bulk storage in the ship's holds for the Boston plan vs. the use of standard containers for the New York City plan. It will be evident that Boston unit costs have been reduced because larger quantities of raw wastes can be taken to sea each trip in the ship's holds than can be carried in standard containers that are poorly suited to the ship's dimensions. Containerization has many important advantages for solid waste storage and

TABLE 2-2

ESTIMATED SHIP INCINERATOR COSTS FOR NEW YORK CITY (1968)

Cost item	2-day Cycle	3-day Cycle	3-Day Cycle with Converted Liberty Ship
1. Vessel Capital Cost	7,625,000	8,317,000	4,775,000
2. Transfer Station Capital Cost	1,150,000	1,250,000	1,020,000
3. Container Cost	880,000	1,520,000	848,000
4. Total Initial Cost	9,666,000	11,087,000	6,646,000
5. Annual Amortization Cost (20 year basis)	753,000	890,000	530,000
6. Annual Vessel Operating Cost	1,004,000	1,004,000	1,004,000
7. Annual Transfer Station Cost	238,000	253,000	235,000
8. Total Annual Cost	1,995,000	2,147,000	1,769,000
9. Annual Tonnage Waste	195,000	234,000	130,000
10. Per ton Cost for Disposal	10.20	9.20	13.60

transport, on land as well as at sea, and it may turn out that container units having dimensions other than 8' x 8' x 38' would be optimum for a converted Liberty Ship. No such restraints apply when designing a new vessel for ocean disposal. More details of the cost breakdowns are contained in the report of the New York City Study(2).

C. SHIP DESIGN

The ship incinerator cost estimates discussed in Section 2-B, above, covered two alternatives: adapting a surplus Liberty Ship to incinerator service vs. constructing a new vessel for this specialized function. The acquisition cost advantage of a surplus ship is offset by a need to fit material handling and burning equipment into the fixed dimensions of an existing structure whereas a new hull can be designed to accomodate waste handling and disposal equipment that has been selected on the basis of its functional superiority.

1. Liberty Ship Conversion

Liberty Ships constructed during the early 1940's do not meet requirements for modern freighters. For example, at a rated speed of 11 knots, they are considered too slow; cargo transfer facilities are limited and, hence, inefficient for economical service. On the other hand, intercontinental freighter service is not a satisfactory criterion to use for judging the adaptability of this vessel to incinerator ship service considering the fact that it is unlikely to ever travel more than

20-30 miles from its home berth or to be at sea for longer than 2-3 days at a time. Some of the operational schedules under consideration suggest that the ship should return to its berth daily. Therefore, the utility of a reconditioned Liberty Ship should be judged solely on its adaptability to the contemplated service requirements.

Figure 2-1 contains sectional views of a standard Liberty Ship showing holds, fuel tanks, engine compartments, crew quarters, and cargo handling equipment. Overall length is 441-5 feet, extreme breadth is 57 feet, and depth to the upper deck is 37.3 feet. Gross tonnage is 7200. Draft is a little less than 28 feet at full design load and a little less than 8 feet without cargo and fuel. As little fuel must be carried for incinerator service and as the density of solid waste is low, vessel draft is unlikely to exceed 18 feet when fully loaded so that little difficulty is anticipated when entering shallow harbors.

In the Liberty Ship, the volume of all cargo holds and deep tanks that are available for incinerator installation and solid waste storage is in excess of one-half million cubic feet. Within these dimension, it is possible to install several incinerators if care is taken to select types which have favorable geometry. The original plan was to utilize two rotary kiln furnaces for mixed rubbish and one special purpose burner for demolition and construction wastes. For preliminary design

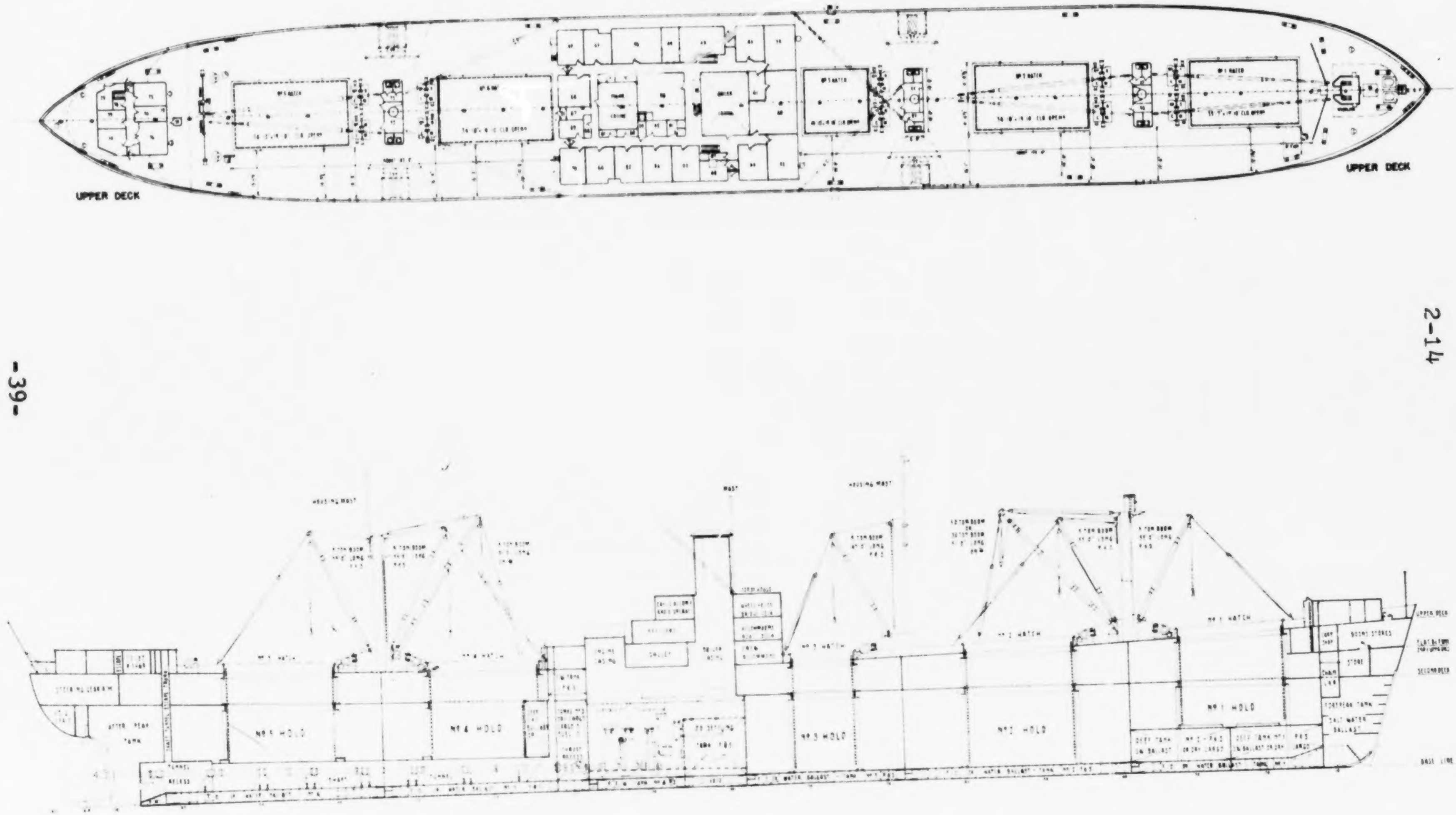
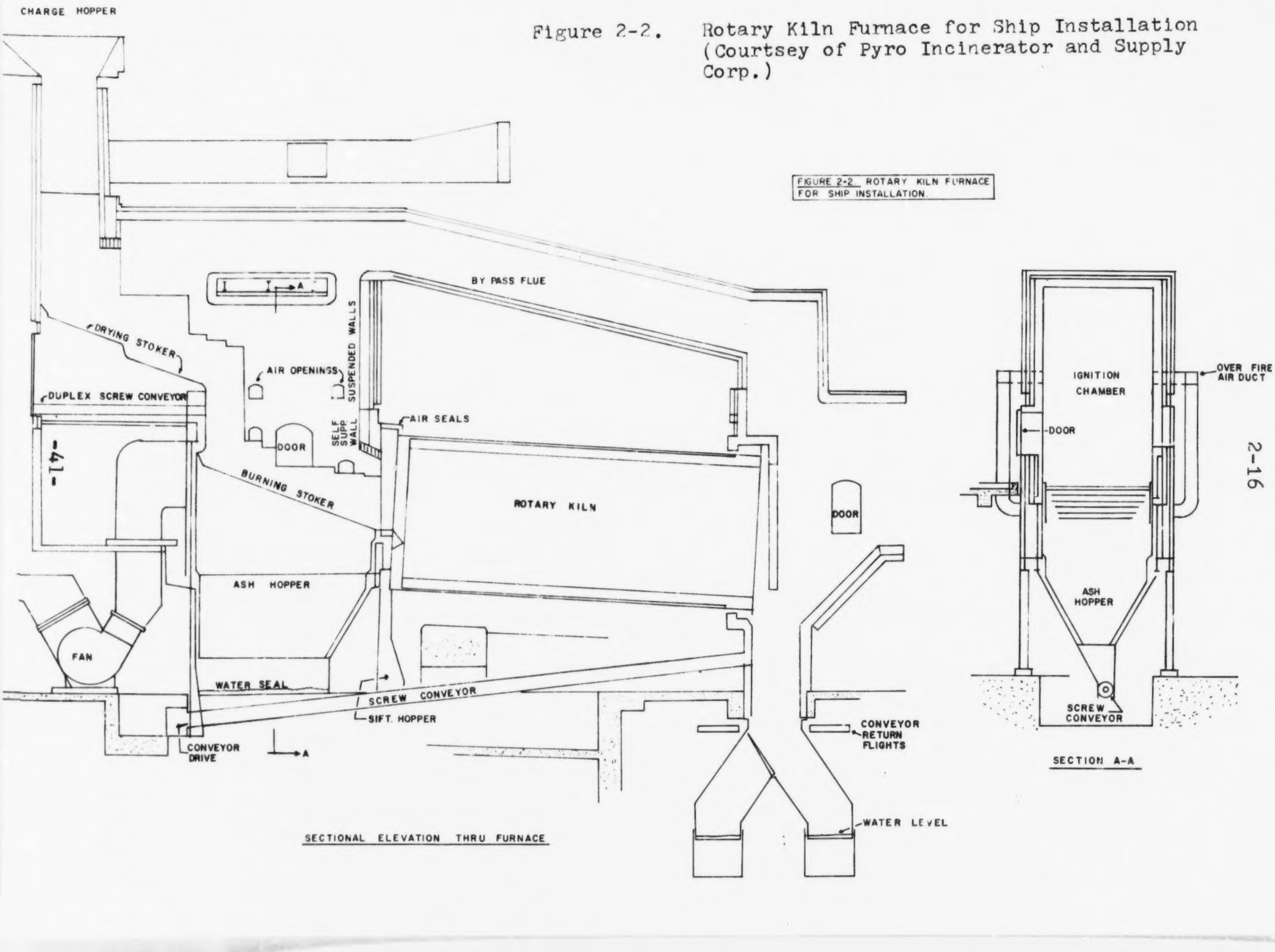

UPPER DECK
UPPER DECK
HOUSING MAST
MAST
HOUSING MAST
Nº 5 HOLD
Nº 4 HOLD
Nº 3 HOLD
Nº 2 HOLD
Nº 1 HOLD
AFTER PEAK TANK
GALLEY
STORE
FOREPEAK TANK
SALT WATER BALLAST
UPPER DECK
SECOND DECK
BASE LINE

Figure 2-1. Liberty Ship Sections (Courtsey of U.S. Maritime Commission, Office of Ship Operations)

purposes, the Pyrofurnace used in Chiago's Southwest Incinerator was selected as the model. Sections of this furnace and associated equipment are shown in Figure 2-2. The length and width of the structures shown are 72 and 15 feet, respectively. The design shown in Figure 2-2 is rated at 300 tons per day, but the capacity can be doubled by increasing the width and length of the drying and burning stokers and increasing the length and diameter of the rotary kiln. If each dimension is increased 41% (i.e., by the square root of two), the net effect will be to double the volume and the daily capacity. This change will make the length of each incinerator approximately 11 feet and the extreme width approximately 20 feet. Referring to Figure 2-1, it may be seen that the Liberty Ship can accomodate two such units forward of the bridge deck; one on either side of the ship's axis as shown in Figure 2-3.

A special purpose furnace for demolition and construction wastes can be located aft of the engine rooms. Because of the bulky nature of these wastes, large holds with wide hatches must be provided for loading and storage. For ease in furnace loading, it may be necessary to reduce the size of the pieces to not more than 2 feet in length by shearing, or some similar method, prior to introducing them into the furnace feed hopper. This may be done by loading the material into an automatic conveyor that will send the feed stock through a shear and/or

Figure 2-2. Rotary Kiln Furnace for Ship Installation (Courtsey of Pyro Incinerator and Supply Corp.)


CHARGE HOPPER
FIGURE 2-2 ROTARY KILN FURNACE FOR SHIP INSTALLATION.
BY PASS FLUE
DRYING STOKER
AIR OPENINGS
SUSPENDED WALLS
DUPLEX SCREW CONVEYOR
AIR SEALS
SELF SUPP. WALL
DOOR
BURNING STOKER
ROTARY KILN
DOOR
ASH HOPPER
FAN
WATER SEAL
SCREW CONVEYOR
SIFT. HOPPER
CONVEYOR DRIVE
A
CONVEYOR RETURN FLIGHTS
WATER LEVEL
SECTIONAL ELEVATION THRU FURNACE
IGNITION CHAMBER
OVER FIRE AIR DUCT
DOOR
ASH HOPPER
SCREW CONVEYOR
SECTION A-A

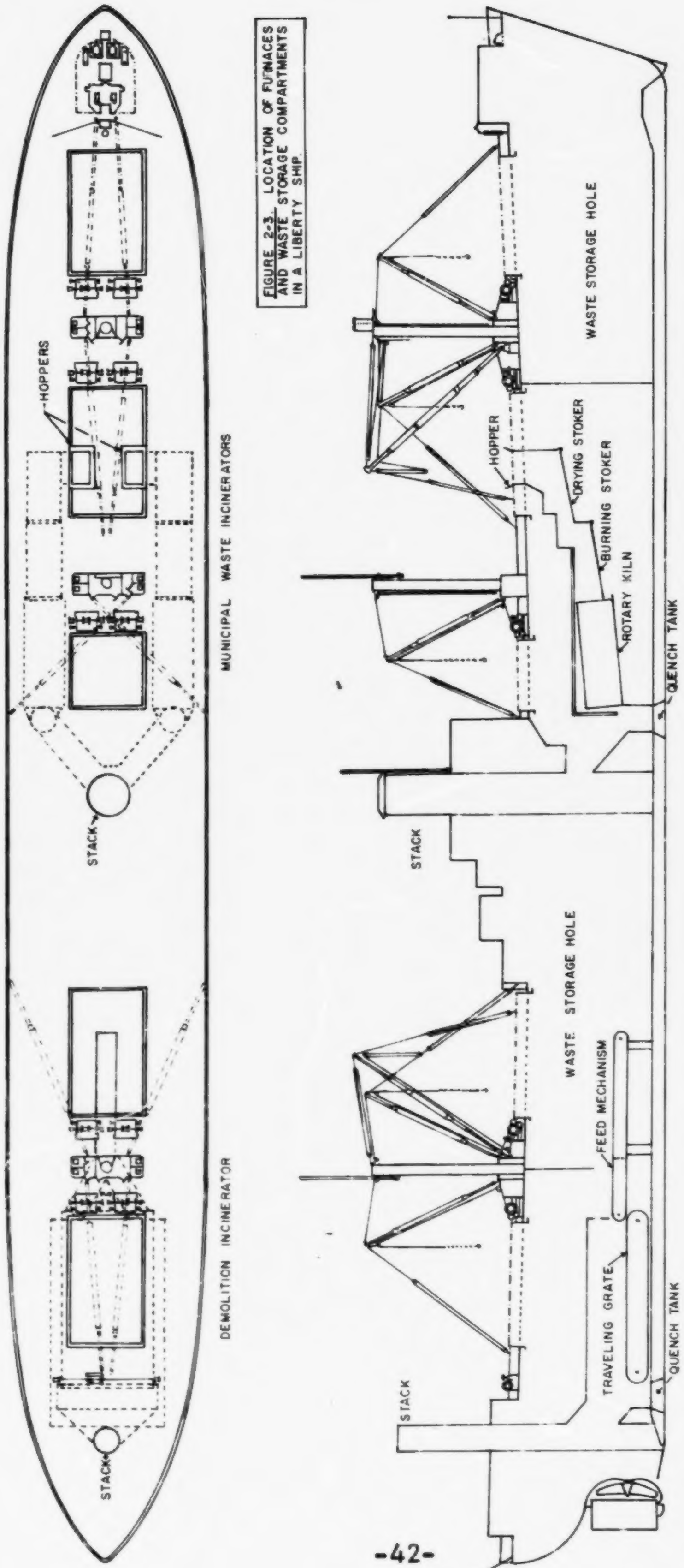


FIGURE 2-3. LOCATION OF FURNACES AND WASTE STORAGE COMPARTMENTS IN A LIBERTY SHIP.
HOPPERS
MUNICIPAL WASTE INCINERATORS
STACK
DEMOLITION INCINERATOR
STACK
WASTE STORAGE HOLE
HOPPER
DRYING STOKER
BURNING STOKER
ROTARY KILN
QUENCH TANK
STACK
WASTE STORAGE HOLE
FEED MECHANISM
TRAVELING GRATE
QUENCH TANK
STACK

Figure 2-3 Location of Furnaces and Waste Storage Compartments in a Liberty Ship

crushing mill on the way to the furnace. The residence time required to destroy construction and demolition wastes is variable and depends on the size and nature of the materials being burned. When construction and demolition (or other bulky) wastes are not available, the special purpose furnace may be used for incinerating mixed municipal wastes and, for this type of service, will have a daily capacity approximately equal to that of each of the two forward incinerators, i.e., 600 tons per day. Figure 2-3 shows the approximate location of furnaces and storage compartments in a converted Liberty Ship. For this plan, the existing cargo handling hoists and booms would be used for waste loading and furnace feeding.

Michaels(2) outlined another Liberty Ship conversion plan which utilized two furnaces having a combined capacity of 1,000 tons per day and containerized waste handling and storage. He proposed removing the existing machinery, cargo handling gear, and most of the shaft tunnel and installing diesel generators and an electric propulsion motor in the present No. 5 Hold. He proposed installing the incinerators in the No. 4 Hold and using the remainder of the hull for stowage and handling of refuse containers. Longitudinal bulkheads were to be installed out-board of the container stowage space to provide the reinforcement needed to compensate for the removal of transverse bulkheads. Part of the deckhouse would be retained for navigation and living space.

Still another Liberty Ship conversion plan considered for application to Boston involved removal of all self-propulsion equipment from the vessel and the use of seagoing tugs for movement. This plan has several advantages: (1) the existing propulsion equipment is obsolescent and overly costly to renovate or replace (2) the space added by removing the propulsion machinery could be used for bulk or containerized waste storage or to provide greater flexibility in locating incinerators (3) maintenance and manning requirements for a towed vessel are substantially less than for a self-propelled Liberty Ship; whereas speed and manueverability are likely to be significantly improved for coastal service. Of the several Liberty Ship conversion plans that were considered, the latter appeared to be the least costly and to have no known disadvantage relative to the remaining conversion alternatives.

2. New Ship Construction

Michaels(2) prepared a preliminary design of a new incinerator ship for the New York City Planning Commission. It was intended to remain at sea for 32-hour burning periods and to use containerized waste handling, storage, and furnace feeding. The ship had a single deck with forecastle and poop. The refuse was to be carried in containers amidships with incinerator and propulsion equipment at the stern, as shown in Figure 2-4. Four watertight transverse bulkheads were needed; one at the fore peak tank, one at the forward

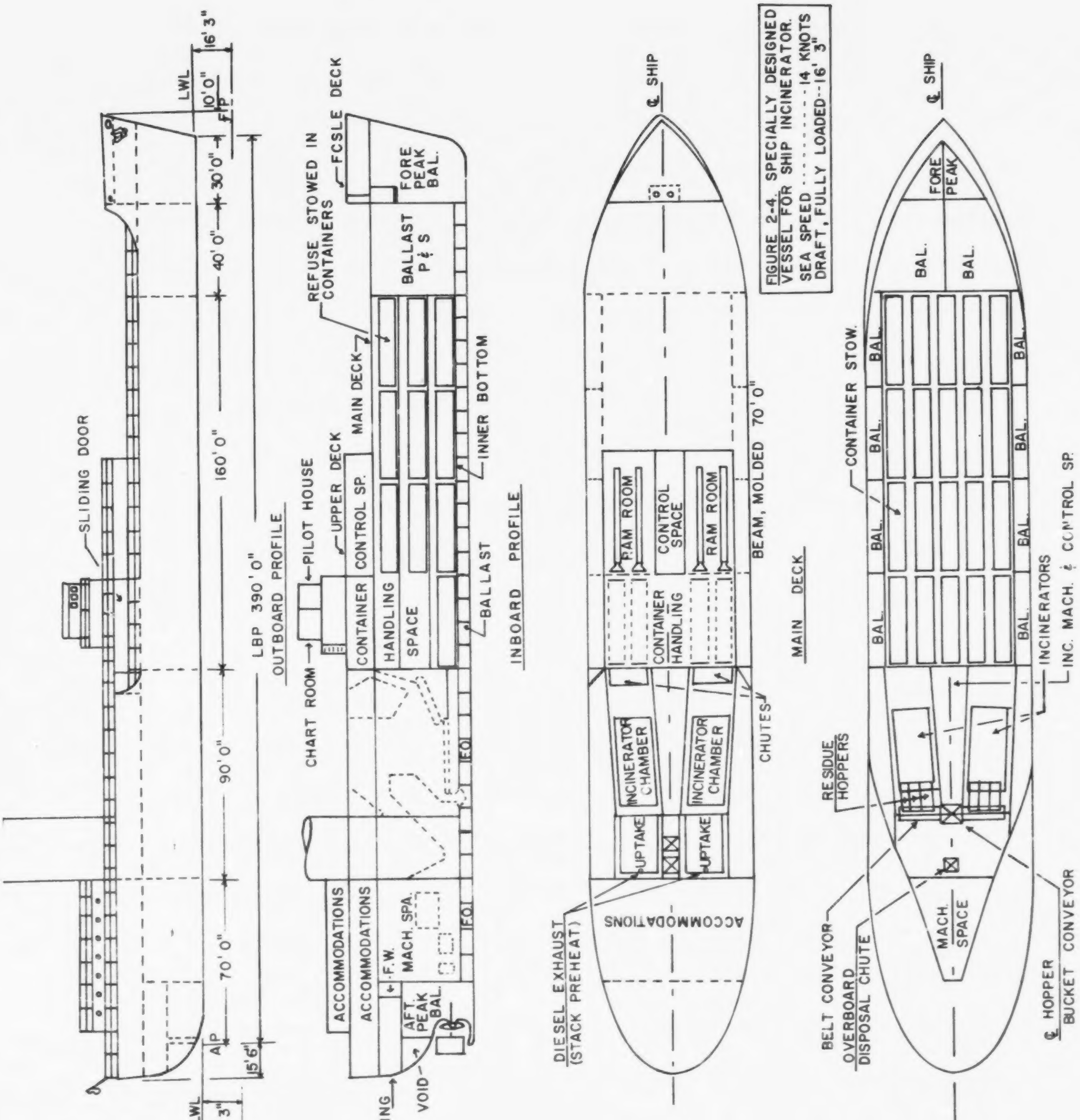


FIGURE 2-4. SPECIALLY DESIGNED VESSEL FOR SHIP INCINERATOR.
SEA SPEED ------14 KNOTS
DRAFT, FULLY LOADED--16' 3"
OUTBOARD PROFILE
SLIDING DOOR
LBP 390' 0"
70' 0"
90' 0"
160' 0"
40' 0"
30' 0"
10' 0"
16' 3"
15' 6"
LWL
A P
F P
INBOARD PROFILE
FCSLE DECK
FORE PEAK BAL.
BALLAST P & S
REFUSE STOWED IN CONTAINERS
MAIN DECK
UPPER DECK
PILOT HOUSE
CHART ROOM
CONTROL SP.
CONTAINER HANDLING SPACE
INNER BOTTOM
BALLAST
ACCOMMODATIONS
ACCOMMODATIONS
F.W.
MACH. SPA.
AFT. PEAK BAL.
FO
FO
STEERING GEAR
VOID
MAIN DECK
℄ SHIP
BEAM, MOLDED 70' 0"
RAM ROOM
CONTROL SPACE
RAM ROOM
CONTAINER HANDLING
INCINERATOR CHAMBER
INCINERATOR CHAMBER
UPTAKE
UPTAKE
CHUTES
ACCOMMODATIONS
DIESEL EXHAUST (STACK PREHEAT)
TANK TOP
℄ SHIP
FORE PEAK
BAL.
BAL.
CONTAINER STOW.
BAL.
INCINERATORS
INC. MACH. & CONTROL SP.
RESIDUE HOPPERS
MACH. SPACE
BELT CONVEYOR
OVERBOARD DISPOSAL CHUTE
℄ HOPPER BUCKET CONVEYOR

Figure 2-4 Specially Designed Vessel for Ship Incineration (Courtesy of A. Michaels)

end of the refuse storage and incinerator compartment, and one at each end of the propulsion machinery space. In addition, a watertight bulkhead formed the boundary between the refuse storage and the incinerator space. Two longitudinal bulkheads in the refuse storage and incinerator spaces formed ballast tanks outboard. Accomodations were provided aft for officers and crew, navigating spaces were located forward of the incinerator stacks, and control and machinery spaces for incinerators and residue handling equipment were located on the centerline of the ship between the incinerator chambers. Access doors were provided to permit servicing and cleaning the stokers. Space for container handling and ram control was located on the main deck at centerline as shown in Figure 2-4.

Propulsion power was provided by two 2200 H.P. Diesel generators through an electric drive to a single screw. The generator exhaust utilized the incinerator chimneys to provide heat for furnace draft during start-up. A single generator was able to furnish the necessary power for the burning operation and to maintain steerage for the vessel. This left one generator on standby for emergency use.

The ship had an overall length of 390 feet, beam of 70 feet, and depth to main deck of 41 feet: It was a shorter but wider vessel than the Liberty Ship. Total dead weight of the ship was 4,200 tons and cost, exclusive of burning equipment and special waste handling, approximately $5 million. This is within the generally accepted marine construction cost of approximately $1,000 per ton.(4)

D. REFUSE HANDLING SYSTEMS

The simplest method of waste collection for ocean disposal would be to utilize an existing system in its entirety except that the location to which the waste would be sent in the pickup vehicles would be to the incinerator ship's berth instead of to a land-based incinerator or landfill location. Many alternate waste transportation and allocation schemes (between simultaneous ocean and land disposal facilities), including the use of transfer stations, have been examined in detail in Section 7, A Simulation Model for Waste Management, and the relative economic advantage of each option has been evaluated.

An artist's conception of a very simple waste loading scheme is shown in Figure 2-5. Here, we see the converted Liberty Ship equipped with two rotary kiln furnaces forward and one special purpose furnace aft for demolition and construction wastes. Collection vehicles are dumping their load within a fenced-in area of the dock beside the vessel and the waste is being loaded into the holds with a clamshell bucket operated with the aid of the ship's cargo handling hoists. The advantages of this waste handling method are simplicity, low cost, and a very brief turnaround time for the collection trucks, but the disadvantages (very long ship loading time and unsanitary conditions) make it impractical and undesirable.

The inset map of Figure 2-5 shows the daily route of an incinerator ship from pickup points (Boston plus North and South Shore cities) to burning grounds.

A slow ship loading method such as that illustrated in Figure 2-5 would seriously reduce the time a vessel could be at sea burning refuse. However, no loading system would be acceptable that required pickup vehicles to be at the dock at precise times for direct loading into the ship or that caused excessive turnaround times because of inadequate unloading facilities. Two ways of avoiding ship or delivery vehicle delay have been considered. In the first, pickup vehicles would discharge their load into one or more storage hoppers located at dockside. The storage silos would be constructed and located to permit rapid automatic unloading directly into a ship's holds. Silo storage would have to be confined to ordinary waste collections as large objects, such as occur in demolition waste, would wedge in the conveying system and make it inoperative. Bulky wastes might be palletized at the collection site or at dockside and loaded into the ship more rapidly in this manner.

The fastest, most economical, and most sanitary method of waste transfer would be by modern container handling techniques. Pickup vehicles might unload directly into standard compactor-containers at dockside which, when filled, would be transferred to the ship in exchange for an equal number of empty containers. Alternatively, wastes might be transferred to standard

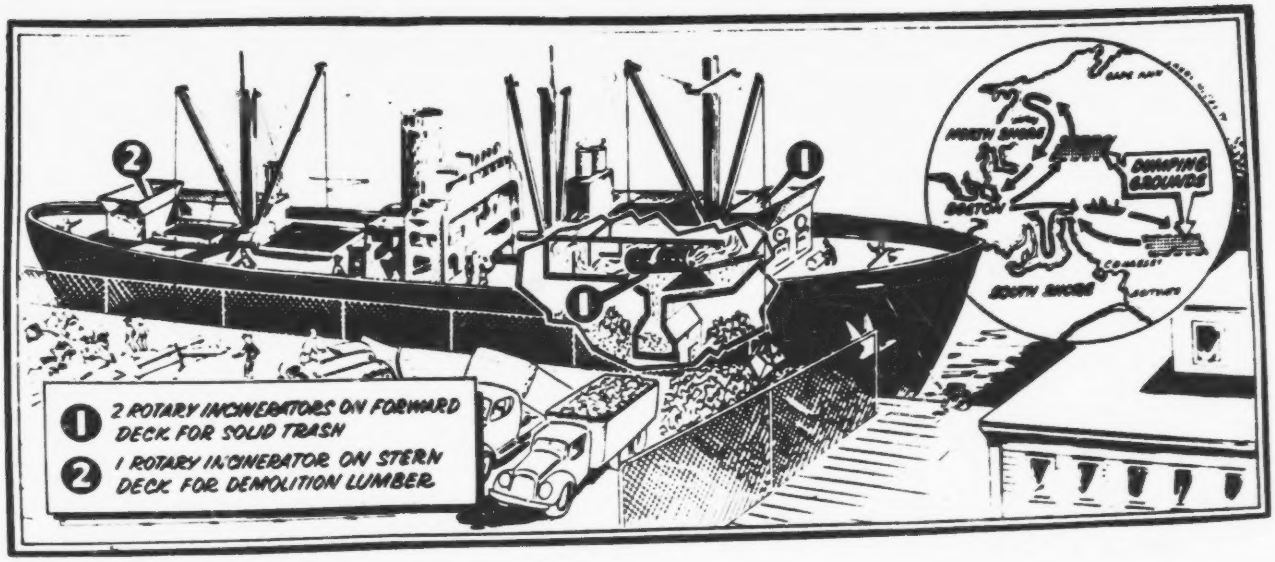

2
1
1
CAPE ANN
NORTH SHORE
BOSTON
DUMPING GROUNDS
SOUTH SHORE
COHASSET
SCITUATE
1 2 ROTARY INCINERATORS ON FORWARD DECK FOR SOLID TRASH
2 1 ROTARY INCINERATOR ON STERN DECK FOR DEMOLITION LUMBER

Figure 2-5. Simple Waste Handling System at Dockside (courtesy of THE BOSTON SUNDAY GLOBE)

compactor-container bodies at remote transfer stations and carried to dockside by tractor. The filled containers would be stored at dockside until the incinerator ship came to pick up its next load and the tractors would return immediately with empty containers from the previous incinerator ship trip. A transfer system of this nature makes it possible to transport full containers to dockside and return empties to transfer stations during late night and early morning hours when road traffic is at its daily minimum, thereby effecting a substantial saving in transportation cost and making it possible to use the tractors for other service during the daytime working hours. Approximately three and a half times the maximum number of compactor-containers that can be carried on the incinerator ship will be required for a remote transfer station operation; i.e., one set on board, one set of empties at dockside, one set of filled containers at the transfer station (to be exchanged for empties at dockside), and one half set for spares, maintenance, repairs, etc.

Figure 2-4 shows Michaels'(2) containerized incinerator ship designed for 50 compactor-containers, each 8 feet x 8 feet in cross section x 38 feet long. They are designed to be stored in four bays in the ship, five abreast, in three levels. The after bay has containers stowed in the lower level, only, on departure as the empty spaces are used to shuttle containers into and out of the refuse discharge points. The incinerator discharge positions are the four lowest positions of the fourth level.

As the compressed refuse can be removed only by forcibly expelling it from the container, they are constructed so that one end is hinged and the other forms a movable bulkhead activated by a piston. Two pistons feed each furnace and it is intended that one container will always be available for charging each furnace.

Details of the feeding devices are shown in Figure 2-6. Means have been provided to (1) move all containers to an incinerator charging position and back to stowage while the vessel is at sea, and (2) remove all empty containers from the ship and replace them with filled ones from the dock. The same handling equipment is utilized for both functions. The containers shown in Figure 2-4 are intended to be stowed on tracks which are attached to the tank top on the lower level and to a steel framework for the upper two levels of bays 1,2, and 3. The containers slide in these lubricated tracks, which prevent athwartship motion, and are provided with individual locking devices to prevent longitudinal motion. Containers are moved into the forward bays from the after bay by a chain which drags them into the same position in the next bay. Except in the after bay, no motion is possible athwartship. At each of the second and third levels on the after bay, two trays are shown which move athwartship and permit outboard containers to be moved into the incinerator feed positions. These trays are power driven on racks to provide resistance to lateral motion by ship rolling. Locking devices prevent longitudinal motion.

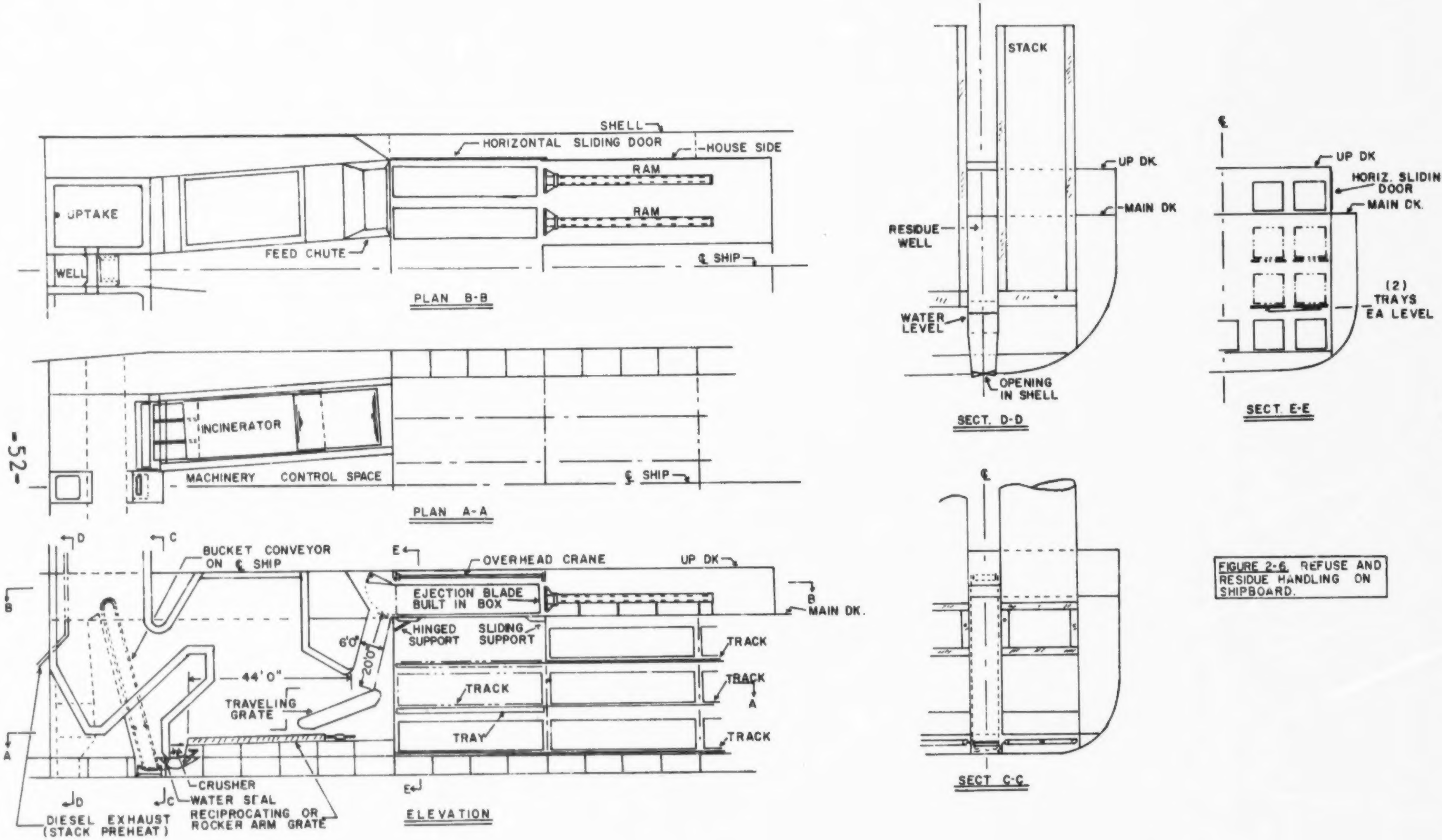

SHELL
HORIZONTAL SLIDING DOOR
HOUSE SIDE
RAM
RAM
UPTAKE
FEED CHUTE
WELL
℄ SHIP
PLAN B-B
INCINERATOR
MACHINERY CONTROL SPACE
℄ SHIP
PLAN A-A
D
C
BUCKET CONVEYOR ON ℄ SHIP
E
OVERHEAD CRANE
UP DK
B
MAIN DK.
EJECTION BLADE BUILT IN BOX
HINGED SUPPORT
SLIDING SUPPORT
6'0"
20'0"
44'0"
TRACK
TRACK
A
TRACK
TRAVELING GRATE
TRAY
TRACK
A
CRUSHER
WATER SEAL
RECIPROCATING OR ROCKER ARM GRATE
DIESEL EXHAUST (STACK PREHEAT)
D
C
E
ELEVATION
℄
STACK
UP DK
MAIN DK
RESIDUE WELL
WATER LEVEL
OPENING IN SHELL
SECT. D-D
℄
SECT C-C
℄
UP DK
HORIZ. SLIDING DOOR
MAIN DK.
(2) TRAYS EA LEVEL
SECT. E-E
FIGURE 2-6. REFUSE AND RESIDUE HANDLING ON SHIPBOARD.

Figure 2-6 Refuse and Residue Handling on Shipboard (Courtesy of A. Michaels)

Above the fourth level in the after bay, a bridge crane is shown which lifts containers from a lower level and permits movement athwartship if no other container is in the way. A track extension is provided for the bridge crane which extends outboard sufficiently from the ship's side to permit container loading and unloading from the dock. This system allows all of the containers to be emptied into the furnaces.

Compactor-containers are estimated to cost about $8,000 each so they represent a substantial part of the total capital investment. However, they permit rapid waste transfer from dock to ship as well as rapid unloading of empties. In addition, the system is probably convertable to an automated transfer system on board for feeding the furnaces which will reduce manpower requirements.

E. INCINERATORS AND RESIDUE DISPOSAL SYSTEMS

Incinerator design must take into account the special limitations imposed by the geometry of a ship and the customary ways in which ship hulls are constructed, stiffened, strengthened, and compartmented for seaworthiness. These restrictions require the use of long, narrow incinerators of moderate height such as the rotary kiln design shown in detail in Figure 2-2 or the traveling and reciprocating grate type suggested schematically in Figure 2-6. In either case, current technology for land based conventional incinerators appears to be adequate for the design and construction of incinerators for shipboard use. Municipal incinerators in large cities utilize furnaces having a daily capacity of 600 tons of mixed refuse and a ship that is 400-500 feet long and 60-70 feet wide can accommodate two to four units of this size.

Land based incinerators conventionally utilize heavy refractory linings in the burning and flue-gas discharge sections of the furnaces. This method of construction is less appropriate for ship service as the constant motion of the vessel at sea is likely to cause shifting of the heavy masonary walls and to be destructive to the fire brick linings. At least one municipal incinerator (Framingham, Mass.) has been constructed with water-cooled metal enclosing walls in place of refractory brick and has operated successfully for a number of years. This furnace has metal mesh traveling grates. Water wall furnaces would be an ideal choice for shipboard use as there is an inexhaustible supply of cooling water immediately available for the cost of pumping and there would be virtually no restrictions on the discharge of the heated water. This type of construction would be strong and would enable the furnaces to resist the destructive action produced by the ship's constant irregular motions.

Figures 2-4 and 2-6 show the completely incinerated residue discharged into a quench tank. For land-based incinerators this practice prevents emission of smoke and odors from the molten residue after discharge and avoid the serious fire hazards associated with the handling of unquenched residue. For shipborne incinerators, the only purpose in having the residue discharge into a quench tank instead of directly into the ocean is to separate floating materials to prevent littering the surface of the ocean in the vicinity of the incinerator ship. The nature and percentages of floating materials in incinerator residues are described in detail in Section 3 of this report. Briefly, it was found that floating material consisted principally of cans and charred wood fragments. When skimmed from the surface of the quench tank, crushed (to collapse cans), dewatered, and recharged to the furnace (to complete combustion of the charcoal), the recycled residue would no longer float when again discharged from the furnace into the quenching tank. The skimming, crushing, dewatering, and recharging processes for handling the floating residues could be automated easily with reliable and readily-available commercial equipment and, as the floatable residues would represent a very small fraction of the total weight charged to the furnace, such a system would require little space and would not be costly.

Discharge of the non-floating incinerator residues could be accomplished continuously by a system such as that illustrated in Figure 2-6. Residue dropping off the end of the stoker grate passes through crushers into a small hopper containing quench and seal water. The residue is pushed out of the quench hopper onto a belt conveyor. This design is similar to that used by the Martin Incinerator. For each furnace, two or three hoppers will be required to reduce lateral water action which would be caused by the roll of the ship. The residue would be carried by the belt conveyor to a bucket conveyor located in the center of the ship which would carry the residue to the top deck and dump it into an open well located in the center of the ship. The well provides for the separation of floating and non-floating materials with the non-floating passing through the well and sinking to the ocean bottom. The floating material would remain on the surface and be removed by a skimming device to be recycled to the furnace.

A small percentage of the non-floating residue is composed of very small particles having a specific gravity only slightly higher than that of sea water. These sink slowly, as described in Section 4-II of this report. If this proved to be a problem during large-scale operations, the non-floating residues could be compacted in a pug mill prior to discharge to insure prompt settlement of all fractions.

F. DISCUSSION

The engineering aspects of municipal solid waste disposal by ocean-going vessels were well developed conceptually during the early phases of this study but detailed engineering development was halted during the latter periods becaused of decisions of the sponsoring organization to emphasize and concentrate on the very important problems associated with the biological effects of incinerator residues on marine organisms and the physical oceanographic impact of residue deposits on the ocean floor. For this reason, many of the proposals contained in this section have not been presented in the amount of detail they require for full understanding and a full examination of their practicality. Mr. Abraham Michaels, Consulting Engineer, was engaged, at our suggestion, by the New York City Department of City Planning to conduct an engineering feasibility study of the ship incinerator concept for New York City. We shared our ideas and data with Mr. Michaels and we have made extensive use of his final report during the preparation of this section. These borrowings have been acknowledged by suitable citations.

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SECTION 3

COMPOSITION OF INCINERATOR RESIDUES AND ANALYSES OF MARINE ORGANISMS

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SECTION 3

COMPOSITION OF INCINERATOR RESIDUES AND ANALYSES OF MARINE ORGANISMS

I. Composition of Incinerator Residues

Melvin W. First

A. Introduction

Incombustible residues from municipal incinerators are extremely variable in composition, reflecting significant geographical and seasonal changes in the raw waste materials charged to the unit as well as differences in incinerator construction and burning efficiency. Therefore, it is difficult to define an "average" or "typical" municipal incinerator residue appropriate for conducting reproducible and standardized studies of the effects of these residues on marine species. Representative municipal incinerator residues were collected from six incinerators in the greater Boston area and examined for important physical and chemical characteristics to help define the average composition and variability around the average of residues produced within a single, relatively homogeneous metropolitan urban area.

B. Sampling Procedures

Because of the heterogeneous nature of the residues, standardized sampling procedures must be followed rigorously to insure the collection of a small representative sample from the enormous output of a large municipal incinerator. Whenever possible, unquenched samples of residue were obtained to avoid loss of soluble fractions and the finest particles with the runoff from excess quenching water. It was relatively easy to obtain unquenched samples as all but the Newton and Salem incinerators used an overhead discharge hopper system for the quenched ash. The ash extraction procedure for sampling was as follows: after completion of the burning cycle (usually left to the discretion of a furnace tender), hot ash was dumped from the furnace through a grating into a closed hopper. With the normally-used quenching water shut off, ash was collected in the hopper until a gross sample of 500-600 lbs. of residue was obtained. From the hopper, it was discharged into a waiting truck and carried to a flat, hard-surfaced place where reduction of sample was begun.

Using the shovel, the gross sample was mixed, heaped into a symetrical mound, and material extracted by the shovelful from the periphery and depths of the pile until a 5 gallon bucket was filled. The filled bucket was weighed, sieved through a 1/2" wire mesh screen onto an open polyethylene sheet. The + 1/2" mesh material was segregated into two piles; metals and cans in one, everything else in another. Each pile was weighed and discarded. The - 1/2" material was retained. This process was repeated until approximately 70,000 g of raw residue was sieved. The combined - 1/2" mesh (approx. 35,000 g) material was thoroughly mixed and the pile was reduced to about 5000 g by coning and quartering.

There were, however, some exceptions to this sampling procedure. Because there was a danger of overheating and cracking the steel collection hopper without the addition of cooling water, ash for sample VII was dumped directly from the furnace to the truck without resting in the hopper. At the Newton incinerator, ash was dropped directly from the grates of the furnace to an underlying quench tank. From there, the quenched ash was carried by conveyor belt to a waiting truck. Because it was impossible to obtain large amounts of unquenched ash from this system without shutting down the furnace completely, it was necessary to take hot ash directly from the operating furnace by shovelsful.

It was difficult to obtain more than a 500 lb. sample of unquenched residue from any incinerator at any one time because of the associated fire hazards. Therefore, this was a limitation on the assumption of a truly representative sample of residue over a protracted time period.

In addition, large "clinkers" (lumps of fused glass and metal, often 200 lbs. each), could not be handled by the sampling procedure that has been described and were not included in any sample. Although exclusion of "clinkers" would probably not effect the chemical and physical values that were obtained with the smaller fragments, omitting clinkers greatly affected the percent of ash greater than 1/2". It is estimated that the reported values of + 1/2" particles may be in error by as much as 10-15 percentage units by the omission of "clinkers".

C. Analytical Procedures

1. Moisture Determination(1)

At the site of collection, a tared wide mouth glass jar with screw cap cover was filled with - 1/2" mesh particles and closed tightly. After return to the laboratory it was weighed to the nearest .0001 g, opened, and dried in a 110°C oven for a period of 12 hours. The bottle was then reclosed, taken from the oven, cooled in a desiccator for an hour and reweighed.

2. Ether Extractable Fats(2)

A 33x94 mm Whatman thimble was dried overnight at 110°C, weighed to the nearest .0001 g, filled with 10-15 g -18 mesh predried ash, redried for 1 hour at 110°C, reweighed, and placed in position in a Soxhlet apparatus. The 250 ml flask of the Soxhlet apparatus was washed with ether, purged of fumes under vacuum, dried for 1 hour at 110°C, desiccated for 20 minutes and weighed to the nearest .0001 grams. After adding 160 ml. of ethyl ether (c.p.) to the flask for fat extraction, the flask was heated and the solvent condenser operated to produce a recycle rate of 4-5 minutes. Extraction continued for 6 hours, after which time the apparatus was dismantled, the thimble removed and dried at 110°C for 24 hours. All remaining ether was carefully drained back into the ether flask, and the flask heated until all the ether was driven off. The flask was then evacuated, dried overnight at 110°C, cooled in a desiccator for 20 minutes, and reweighed to the nearest .0001 g. Percent of ether-extracted fats was calculated on the basis of the weight gain of the flask because it was found that the weight loss of the cellulose thimble was less reliable because of rapid moisture gains and losses.

3. Combustible(3)

Vycor crucibles were fired over a Bunsen burner for a period of 5-10 minutes. After cooling in a desiccator for 20 minutes, they were weighed to constant weight. Approximately 7 g of - 18 mesh ash was placed in each crucible and they were reweighed after drying at 110°C for 1 hour. The covered crucibles were then placed into a preheated muffle furnace set at 800°C, and heated for 24 hours. After cooling in a desiccator, the crucibles were reweighed and the percent combustibles calculated from the weight loss.

4. Particle Size(4)

Approximately 400 g of sample was placed in the top of a 10 in. bundle and mechanically shaken for 20 minutes. Each fraction was weighed on an analytical balance and the cumulative percent by weight equal to or less than each sieve opening was used to plot a log-probability size curve from which the mass median diameter and geometric standard deviation were obtained. The sieve bundle consisted of a U.S. Series 4 and 14 plus a Tyler Series 30, 50, 100. This corresponds closely to a standard Tyler series of the square root of two. Care was taken to recover +99% of the material charged to the sieves, which falls within ASTM accepted standards.

5. Composition of the - 1/2 inch, +12 Mesh Fraction

Approximately 200 g of -1/2 inch residue was sieved on a 12 mesh screen for 20 minutes and the + 12 mesh material was hand-segregrated into a number of categories based on appearance, i.e., stone, glass, metal, etc. Each category was weighed separately and the percent of each recorded.

6. Floatable Material, - 1/2 in., + 18 Mesh in Size

Approximately 100 g of + 18 sieved residue was placed in a 250 ml beaker, radius 3.5 cm, and 200 ml of liquid (either distilled or sea water) added. The slurry was stirred, allowed to rest for a minimum of 3 hours, stirred again and then, after another settling period, the floating material was poured off into a predried and preweighed analytical filter paper and vacuum filtered. After all the floating material was on the filter, it was washed 3 times with distilled water, dried for a minimum of 12 hours at 110°C and weighed to the nearest .001 g. The first filtrate (before washing) was collected and the pH determined with an automatic Leeds & Northrup instrument. The percent floatable was calculated on the weight of the total residue charged to the beaker.

7. Floatable Material - 18 mesh

Approximately 4 g of - 18 mesh sieved residue was placed in a 250 ml beaker with 200 ml of liquid consisting of distilled or sea water plus 3% Alconox. After stirring and settling for 3 hours, all the floating material was removed with the aid of a suction tube, transferred to a preweighed sintered glass filter, washed 3 times in distilled water and dried for a minimum of 12 hours at 110°C. The percent floatable in the -18 mesh fraction was calculated on the basis of the total weight of sample introduced to the beaker.

8. Solubility(5)

Five grams of -18 mesh residue was placed in 100 ml. of solvent (distilled or sea water), stirred, and allowed to remain in contact for 12 hours. The insoluble residue was filtered through a predried and weighed medium glass sintered funnel filter, washed three times with distilled water, dried 12 hours at 110°C, and weighed to constant weight. There was a modification of this procedure for salt water because of the residual salt remaining on the particles after drying.

After the salt water and residue were filtered, the filter was weighed wet, dried for 12 hours at 110°C, and reweighed. The difference in weight was the amount of water evaporated. This weight, multiplied by .0317 gave the amount of sea salt left behind in the dried residue and was subtracted from the observed weight of the ash on the filter to give the true amount of insoluble ash remaining. The percent solubility was calculated from the weight loss (after correction in the case of salt water solubility).

D. Sampling Sites

A total of 41 samples was collected for analysis from 14 separate municipal incinerators in the Greater Boston area over a two year period. The sites, number of samples, type of furnaces, and burning rate are summarized in Table 3-1. Except for the Boston municipal incinerator, two or more individual 500 lb or greater samples were collected and reduced to a laboratory size during a single day's visit. A total of ten samples was collected from the Boston incinerator on four different dates. In the following summary tables of analytical results, the mean values represent the average of all samples collected at each site unless they are designated by a Roman numeral; in which case only the result from that particular sample is indicated. The emphasis on samples from the Boston municipal incinerator reflects the fact that it is the largest in the area, is fairly modern and hence representative of current practices, and, because it serves the core city, handles the most diverse types of waste collections in the area.

TABLE 3-1

MUNICIPAL INCINERATORS SAMPLED

City	Date	Sample No's.	Type Furnace	No. Units	Actual Burning Rate
Belmont	8/13/64	XXIV, XXV	Rotary Circular	2	40-45 T/8 hrs.
Boston	6/24/63	IV, V	Rectangular Rocking Grates	6	400-500 T/24 hrs.
	6/26/63	I, II, III			
	7/16/63	VI, VII, VIII			
	8/4/65	XXXII, XXXI			
Brookline	8/7/63	XIII, XIV, XV	Nichols Monohearth	2	80 T/8 hrs.
Dedham	8/22/63	XVI, XVII	Pyro Incinerator	2	25-28 T/8 hrs.
Framingham	8/21/64	XXVI, XXVII, XXVIII	Rectangular Rocking Grates	2	150 T/24 hrs.
Marblehead	8/28/64	XXIX, XXX	Rectangular Rocking Grates	2	35-40 T/12 hrs.
Newton	7/31/63	IX, X	Hiller Furnace	2	170-200 T/24 hrs.
Salem	8/7/64	XX, XXI, XXII, XXIII	Rotary Circular	2	230 T/24 hrs.
Somerville	8/5/64	XXXIII, XXXIV	Rotary Circular	3	200 T/24 hrs.
Watertown	8/26/63	XVIII, XIX	Nichols Monohearth	2	86 T/8 hrs.
Waltham	8/13/65	XXXIX, XXXX XXXXI	Rectangular Rocking Grates	2	100 T/24 hrs.
Wellesley	8/2/63	XI, XII	Nyland Furnace	2	50-55 T/8 hrs.
Weymouth	8/11/65	XXXV, XXXVI	Rotary Circular	2	300 T/24 hrs.
Winchester	8/12/65	XXXVII, XXVIII	Rectangular Rocking	2	35 T/8 hrs.

At a later time, the Boston municipal incinerator served as the sole source of all the residue used for the biological and oceanographic studies described in later sections.

E. Results

1. Fraction of Particles over 1/2 inch

The percentages of tin cans and other items greater in size than 1/2" are shown in Table 3-2. The spread in values reflects the fact that the composition depends on the type of material burned and residential cities are likely to have a different mix than core cities such as Boston and industrialized communities such as Watertown. Tin cans represent about 15% by weight of the total residue from the 10 incinerators tested and total material greater than 1/2-inch in size comprised one-half to 80% of the total with 50-60 representing the modal values. These figures indicate that only a lessor fraction of the residue was saved for more detailed analysis. From the viewpoint of chemical activity, physical dispersion in the environment, and biological effects, the smaller particles that were retained represented the fraction of interest. As solubility, toxicity, and other physical and chemical reactions and effects of interest are related to specific surface rather than to total weight alone, the discarded fraction, e.g., tin cans, rocks, and gross metal objects, are of little significance.

2. Particle Size.

Particle size distributions of the under 1/2-in. fraction are shown in Table 3-3. The mean values range from a

Table 3-2

PERCENT OF TOTAL PARTICLES GREATER THAN 1/2" AND PERCENT TIN CANS IN RESIDUE DISCHARGED FROM INCINERATORS

All Particles > 1/2 inch			Tin Cans	
City	Mean Value (%)	Range (%)	Mean Value (%)	Range (%)
Belmont	59	58-60	11	10-12
Boston	55	65-50	18	21-16
Brookline	63	60-66	13	16-10
Dedham	56	61-51	11	12-10
Framingham	80	76-84	16	14-19
Marblehead	50	37-64	15	14-15
Newton	77	79-74	24	20-27
Salem	59	49-59	16	15-16
Watertown	48	53-44	13	13-12
Wellesley	47	53-40	14	18-10

TABLE 3-3

SIZE DISTRIBUTION OF THE UNDER 1/2-in. RESIDUE

SOURCE	MMD(mm)	RANGE (mm)
Belmont	1.9	1.8-2.1
Boston	3.5	2.3-5.4
Brookline	1.6	.80-2.5
Dedham	1.9	1.8-2.0
Framingham	2.1	1.8-2.3
Marblehead	1.2	1.1-1.3
Newton	1.3	.84-1.8
Salem	1.4	1.2-1.6
Somerville	2.7	2.3-3.2
Watertown	1.3	1.2-1.4
Waltham	1.9	1.6-2.3
Wellesley	2.5	2.0-2.9
Weymouth	2.0	1.5-2.4
Winchester	1.7	1.2-2.3

TABLE 3-4

MOISTURE CONTENT OF THE UNDER 1/2 INCH RESIDUE

City	Mean Moisture Content (%)	Range (%)
Boston	.05	.02-.10
Brookline	--	.02-8.3
Newton	.13	.06-.19
Watertown	7.9	6.2-9.7
Wellesley	.54	.10-.98

high of 3.5 mm in Boston to a low of 1.2 mm in Marblehead. As particle size is affected by rate and efficiency of combustion, the type of material burned, the weather, and the collection day, it seems reasonable to find a wide size spread in the mean size values. All but one of the mean values ranged between 1 and 3 mm; somewhat less variability than was observed for most characteristics.

3. Moisture.

The moisture content of five samples of - 1/2 inch residues are shown in Table 3-4. As most of the samples were not taken directly from the furnaces but were first passed through the collecting hopper to the transfer truck, there were uncontrolled opportunities for the residues to pick up any residual water that might have remained in the truck or hopper from previous routine operations. Therefore, the results reported in Table 3-4 are very variable in some cases; notably for the Brookline incinerator samples. On the other hand, the Boston incinerator samples were consistently low.

4. Combustible.

The percent combustible matter shown in Table 3-5 represents a substantial fraction of the under 1/2-inch residue in all communities except Newton. The Newton value was low because the sample may have been drawn from an area where the residue had been lodged in the furnace grates for an extended period because of the peculiar sampling procedure that was required to bypass the quench tank. For this reason, the Newton

TABLE 3-5

COMBUSTIBLE MATTER IN THE UNDER 1/2-in. RESIDUE

City	Mean Value (%)	Range (%)
Boston	14	9.0-21
Brookline	28	22-35
Dedham	14	13-14
Newton	3.9	2.1-5.4
Watertown	15	10-18
Wellesley	24	19-30

TABLE 3-6

ETHER SOLUBLE FRACTION IN THE UNDER 1/2-in. RESIDUE

City	Mean Value (%)	Range (%)
Boston	.28	.12-.51
Brookline	.12	.03-.20
Dedham	.10	.096-.10
Newton	.18	.08-.27
Watertown	.07	.056-.084
Wellesley	.25	.11-.39

value should be accepted with reservations. An examination of the under 1/2-inch fraction suggested that the principal combustible component was charred wood fragments, i.e., wood charcoal. There was no other evidence of poor combustion in the residue samples that were collected from the incinerators, e.g., the presence of organic materials. These small fragments of wood charcoal represented a major fraction of all non-wettable and floatable matter.

5. Ether Soluble.

Samples from all six cities yielded very nearly the same fat or ether soluble content in their residues, as shown in Table 3-6. This small ether soluble fraction, which ranges around .20%, represents a residue of oily or waxy matter of unknown composition and unknown origin.

6. Solubility.

The results of solubility tests in distilled water are shown in Table 3-7. Only ash of -18 mesh size was used to maximize exposed surface per gram and, thereby, to increase solubility rate. In fresh water, values from a high of 13% in Weymouth to a low of 0.35% in Winchester were obtained. As noted above, the solubility test in sea water is more difficult because the ash absorbs salts from the sea water. When sea water solubility results shown in Table 3-8 are compared with distilled water results shown in Table 3-7, it is obvious that, for most samples, the results are closely similar, indicating that sea water has no special solvent action on these incinerator residues.

TABLE 3-7

SOLUBILITY OF - 18 MESH RESIDUE IN DISTILLED WATER

City	Mean Value (%)	Range (%)
Belmont	2.0	0.12-4.0
Boston	2.7	1.2-6.1
Brookline	3.9	1.0-5.6
Dedham	1.3	.91-1.8
Framingham	4.0	4.0
Marblehead	4.0	2.0-6.0
Newton	1.1	.27-1.7
Salem	5.0	4.0-6.0
Somerville	4.0	2.0-6.0
Waltham	8.0	6.0-10
Watertown	1.7	1.7-1.8
Wellesley	2.4	1.2-3.8
Weymouth	13	5.4-20
Winchester	0.35	0.10-0.60

TABLE 3-8

SOLUBILITY OF - 18 MESH RESIDUE IN SEA WATER

City	Mean Value (%)	Range (%)
Belmont	12	2.6-21
Dedham	1.0	--
Framingham	4.2	4.2
Marblehead	7.2	2.2-12
Salem	5.2	2.2-8.4
Somerville	6.1	2.0-10
Watertown	1.5	--
Waltham	3.2	2.2-4.2
Weymouth	12	6.0-17
Winchester	7.4	6.0-8.8

When identical tests were conducted on the +18 mesh fractions of the same residue samples it was found that in every case the solubility of the larger fraction was less than that of the smaller fraction. The results of both solubility tests with the larger fraction are shown in Table 3-9. These results confirm the importance of particle size (and, hence, specific surface) for solubility and for many other physical and chemical properties of the residue. Among the soluble ions in either solvent are metals, nitrates, sulfates, chlorides and phosphates. Nitrates and phosphates are often "limiting factors" in the growth of ocean phytoplankton and any increase in these ions would increase growth rate. Added iron would stimulate the growth of diatoms$^{(6)}$. With respect to chlorides, even sensitive fish can withstand a 2% shift in salinity.

7. pH

Changes in pH are an important result of residue solubility. Because sea water has considerable buffering action, soluble matter from the residue raised the pH of sea water from a normal value of close to 8 for most sea water samples to approximately 9 (Table 3-11) whereas the effect on distilled water was to raise the pH level to about 11 in a large number of cases (Table 3-10). The observed differences in pH reflect the composition of the material charged to the incinerator prior to withdrawing a sample. The presence of large amounts of bone and wood ash, for example, would be effective in raising the pH ab-

TABLE 3-9

SOLUBILITY OF + 18 MESH RESIDUE

A. Solubility in Distilled Water

City	Mean Value (%)	Range (%)
Belmont	0.61	0.41-0.81
Framingham	1.9	1.1-2.6
Marblehead	1.4	1.2-1.5
Salem	0.99	0.79-1.2
Somerville	0.60	0.60
Waltham	0.55	0.30-0.70
Weymouth	5.9	0.35-11
Winchester	0.28	0.28

B. Solubility in Sea Water

City	Mean Value (%)	Range (%)
Belmont	2.3	0.36-4.2
Framingham	1.9	1.2-2.6
Marblehead	0.92	0.92
Salem	0.86	0.79-0.92
Somerville	3.8	3.2-4.4
Waltham	0.45	0.20-0.70
Weymouth	5.9	0.76-11
Winchester	0.24	0.24

TABLE 3-10

pH OF DISTILLED WATER EXTRACTS OF RESIDUES

A. - 18 Mesh Fraction

City	Mean Value (%)	Range (%)
Belmont	8.8	8.5-9.0
Boston	9.2	8.8-10.0
Brookline	10.3	9.8-10.5
Dedham	11.4	11.2-11.6
Framingham	11.4	10.9-12.0
Marblehead	10.8	10.4-11.3
Newton	11.1	11.0-11.3
Salem	8.0	7.9-8.2
Somerville	11.3	11.1-11.6
Waltham	11.1	10.5-11.7
Watertown	11.4	11.0-11.9
Wellesley	10.3	10.2-10.4
Weymouth	8.3	7.4-9.2
Winchester	8.5	8.3-8.8

B. + 18 Mesh Fraction

Belmont	8.9	8.6-9.3
Boston	9.9	8.9-10.9
Brookline	10.1	10.1
Dedham	9.7	9.5-9.8
Framingham	10.1	9.1-11.1
Marblehead	9.7	9.2-10.2
Newton	10.8	10.8-10.9
Salem	7.9	7.9
Somerville	10.5	9.6-11.3
Waltham	10.0	9.7-10.3
Watertown	10.0	9.7-10.2
Weymouth	7.6	7.4-7.8
Winchester	9.7	8.3-11.0
Wellesley	10.0	9.7-10.3

TABLE 3-11

pH OF SEA WATER EXTRACTS OF RESIDUES

A. - 18 Mesh Fraction

City	Mean Value (%)	Range (%)
Belmont	8.3	8.2-8.5
Boston	8.7	8.4-9.0
Brookline	9.2	9.0-9.5
Dedham	9.1	9.0-9.2
Framingham	9.5	9.4-9.7
Marblehead	9.2	9.1-9.3
Newton	9.1	8.9-9.4
Salem	7.9	7.8-8.0
Somerville	9.5	9.5-9.6
Waltham	9.5	9.3-9.7
Watertown	9.2	8.9-9.3
Wellesley	9.3	9.2-9.4
Winchester	8.7	8.2-9.3
Weymouth	8.1	7.5-8.8

B. + 18 Mesh Fraction

Belmont	8.4	8.0-8.8
Boston	8.6	8.5-8.9
Brookline	9.0	8.9-9.0
Dedham	8.6	8.3-8.8
Framingham	8.7	8.4-9.1
Marblehead	8.2	8.2-8.3
Newton	9.3	9.2-9.3
Salem	7.6	7.6-7.7
Somerville	8.7	8.3-9.2
Waltham	8.8	8.5-9.2
Watertown	8.6	8.5-8.6
Wellesley	8.6	8.5-8.6
Weymouth	7.3	7.2-7.4
Winchester	9.5	9.1-10.0

normally, whereas a poorly burned sample containing protein and fats might retain abnormally high percentages of water soluble organic acids that would tend to depress the pH. The degree of solubility from incinerator to incinerator is marked (considering the fact that the pH is a logarithmic value) whereas the variability from sample to sample from the same source tends to be low. This suggests that the observed variability between incinerators is related principally to the raw waste composition.

8. Floatable Materials.

Results of measurements of the floatable fraction of the residues are shown in Tables 3-12, 3-13, and 3-14. It is important that no materials be placed in the oceans that will float on the surface and possibly wash back to shore. Of the + 18 mesh residue, only about 1% is floatable in distilled water and of this amount almost all is wood-charcoal fragments and scraps of paper and paper ash. Because of the increased buoyancy of sea water, a larger weight fraction of the +18 mesh residue floats. The major problem with - 18 mesh residues is wetting each particle. This is demonstrated by comparing the percentages of - 18 mesh residues that float in plain sea water (Table 3-13) with the percent that floats in sea water containing a wetting agent such as 3% Alconox, Table 3-14. As much as 40% by weight of fine residue particles float in plain sea water compared with approximately 0.5% floatable when a wetting agent is added. This demonstrates the importance of thoroughly wetting the incinerator residues prior to placing them in water if a floating layer is to be avoided. When hot particles are dumped from furnaces directly into a quench tank, wetting seems to be no problem.

TABLE 3-12

FLOATABLE FRACTION IN DISTILLED WATER

A. - 18 Mesh Fraction

City	Mean Value (%)	Range (%)
Belmont	15	10-20
Boston	28	5.0-51
Brookline	10	2.9-17
Dedham	7.2	2.2-12
Framingham	4.3	4.0-4.6
Marblehead	32	29-36
Newton	2.9	2.5-3.4
Salem	26	25-27
Somerville	42	36-48
Waltham	17	8.0-26
Watertown	21	18-24
Wellesley	20	14-25
Weymouth	4.8	4.2-5.4
Winchester	3.8	3.6-4.0

B. + 18 Mesh Fraction

City	Mean Value (%)	Range (%)
Belmont	0.69	0.59-0.79
Boston	1.4	.51-2.3
Brookline	5.3	4.6-5.8
Dedham	.63	.57-.68
Framingham	2.7	1.8-4.7
Marblehead	5.3	3.5-7.1
Newton	.51	.40-.61
Salem	3.8	3.3-4.2
Somerville	1.6	1.3-1.8
Waltham	0.98	0.15-1.8
Watertown	6.4	--
Wellesley	1.2	1.1-1.3
Weymouth	2.0	1.8-2.3
Winchester	1.5	0.86-2.1

TABLE 3-13

FLOATABLE FRACTION IN SEA WATER

A. - 18 Mesh Fraction

City	Mean Value (%)	Range (%)
Belmont	29.20	15-44
Boston	42	13-72
Brookline	28	13-41
Dedham	15	3.6-27
Framingham	37.30	30-45
Marblehead	36.20	30-42
Newton	4.1	4.1
Salem	32.90	20-46
Somerville	47.90	48
Waltham	21.20	9.6-33
Watertown	35	31-39
Wellesley	26	16-35
Weymouth	12.30	4.6-20
Winchester	6.40	6.4

B. + 18 Mesh Fraction

City	Mean Value (%)	Range (%)
Belmont	0.99	0.99
Boston	2.5	1.2-4.1
Brookline	6.3	3.8-8.0
Dedham	.80	.80
Framingham	3.6	2.6-4.7
Marblehead	8.1	6.1-10
Newton	1.6	1.4-1.9
Salem	8.1	5.5-11
Somerville	2.6	2.5-2.8
Waltham	2.0	0.26-3.6
Watertown	12	7.6-15
Wellesley	3.3	2.8-3.8
Weymouth	4.0	3.7-4.3
Winchester	2.1	2.1

TABLE 3-14

FLOATABLE FRACTION OF - 18 MESH RESIDUES IN SEA WATER CONTAINING 3% ALCONOX

City	Mean Value (%)	Range (%)
Boston	.60	1.3-1.7
Brookline	.88	.67-1.1
Dedham	.51	.50-.52
Newton	.50	.24-.76
Watertown	.66	.61-.71
Wellesley	.78	.54-1.0

II. Chemical Analyses of Incinerator Residues, Bottom Sediments, and Marine Organisms

Janet W. Cares

A. Introduction

These analyses have been concerned primarily with trace heavy metals which might dissolve in the marine environment and concentrate in marine organisms, causing damage to the organisms or to their predators, including man. Methods have been developed for the determination of a number of trace metals in incinerator residues and marine life including the analysis of iron, copper, lead, zinc, manganese, cobalt, chromium, nickel, and cadmium. These metals have special importance because of their known toxicity to marine life and humans and because they are found in measurable quantity in incinerator residues.

Two basic methods of analysis were investigated: atomic absorption and x-ray emission spectrometry (x-ray fluorescence). In succeeding sections the relative merits of these methods are discussed and results are presented and evaluated.

B. Incinerator Residues

1. Analytical Methods

a. Analysis by X-Ray Fluorescence

In this method the residue samples were ground and sieved, mixed in definite proportion with borax, pelletized, and the secondary x-rays produced by irradiation of trace metals in the samples quantitated (See Appendix 3-II). A modified x-ray procedure applied successfuly to air samples(2) has the advantage that it is not necessary to put samples into solution for analysis, thus there can be no loss of metal due to incomplete solubility or to volatilization. It is particularly useful for incinerator residue, which is already in the proper physical form and contains relatively large amounts of several of the metals sought. It does not have sufficient sensitivity for the low concentrations of cadmium, chromium, cobalt, or nickel found in incinerator residues or for concentrations of trace metals found in marine organisms.

b. Analysis by Atomic Absorption

In this method samples were dried, ignited, dissolved in acid, filtered, and after making to volume, analyzed for trace metals (see Appendix 3-I). This method has greater sensitivity than the x-ray method and is therefore applicable to analyses of trace metals in marine organisms (Table 3-15). It is subject to some interferences which must be compensated for before the method may be used with complete confidence.

c. Comparison of Methods

X-ray fluorescence and atomic absorption have certain advantages when applied to the analysis of incinerator residues. Table 3-16 shows the greater sensitivity of the atomic absorption method. Although x-ray limits are omitted in several cases, they would be of the same order of magnitude as those given. It is evident that the low concentration of cadmium, chromium, cobalt, and nickel could not be measured reliably by x-ray. In theory, the detection limit for manganese should be adequate, however known concentrations made up from different manganese compounds gave widely varying results. Samples were analyzed by both methods for copper, iron, lead, and zinc. The ratios of results by both methods are presented in Table 3-17. All agree within 17% except zinc, which is 33% lower by x-ray than by atomic absorption.

Although the variability appears high, it must be compared with the variability between samples by the individual methods. This is shown in Table 3-18 and is based on results of analysis of samples 1 through 6, including 4E. Some variability in both types of samples would be expected merely from slight inhomogeneity of the sample as well as normal errors in weighing or dilution. With atomic absorption there is the additional factor of solubility, as well as the effect of other salts in solution. With the x-ray method, errors of dilution and homogeneity of the sample are magnified. According to work done at Drexel,(3) it is necessary to analyze 25 separate aliquots of a single sample in order to achieve a standard deviation of 5%.

Table 3-19 compares results of analysis by atomic absorption of incinerator residue #4 by two laboratories. The "Rhode Island" results represent those obtained by a single analysis by Dr. Ronald Eisler of the National Marine Water Quality Laboratory at West Kingston, Rhode Island. A Perkin-Elmer model 303 spectrophotometer was used, and ash was digested overnight in 6N HCl. The "Harvard" results are an average of several sample aliquots

TABLE 3-15

APPROXIMATE DETECTION LIMITS OF TRACE METALS IN MARINE ORGANISMS BY ATOMIC ABSORPTION
(micrograms per gram)

	Average Weight (g)	Cd	Cr	Co	Cu	Fe	Pb	Mn	Ni	Zn
Winter Flounder										
Whole	20	0.02	0.5	0.15	0.03	0.25	0.25	0.07	0.70	0.02
Bone	10	0.04	1.0	0.30	0.06	0.50	0.50	0.14	1.40	0.04
Gills	2	0.20	5.0	1.5	0.30	2.5	2.5	0.70	7.0	0.20
Gut	3.5	0.11	2.9	0.86	0.17	1.5	1.5	0.40	4.0	0.11
Liver	2	0.20	5.0	1.5	0.30	2.5	2.5	0.70	7.0	0.20
Muscle	26	0.02	0.4	0.12	0.02	0.20	0.20	0.05	0.54	0.02
Skins	9	0.04	1.1	0.33	0.07	0.55	0.55	0.16	1.56	0.04
Scallops										
Whole	85	0.005	0.1	0.04	0.01	0.05	0.05	0.02	0.16	0.005
Gills	5.5	0.07	1.8	0.55	0.11	0.90	0.90	0.25	2.5	0.07
Muscle	20	0.02	0.5	0.15	0.03	0.25	0.25	0.07	0.70	0.02
Mantle	8	0.05	1.3	0.37	0.07	0.65	0.65	0.18	1.75	0.05
Gonads	6	0.07	1.7	0.50	0.10	0.85	0.85	0.23	2.3	0.07
Liver	4.5	0.09	2.2	0.67	0.13	1.1	1.1	0.31	3.1	0.09
Quahog										
Whole	11	0.03	0.9	0.27	0.05	0.45	0.45	0.13	1.3	0.03

TABLE 3-16

Detection Limits in Parts per Million for Various Elements in Incinerator Residue*

	Range in Ash Samples 1-6	Detection Limit (ppm) X-Ray	Detection Limit (ppm) Atomic Absorption
Cadmium	9.1 - 16.0	---	0.25
Chromium	41 - 120	---	7.5
Cobalt	16.5 - 33.0	---	3.75
Copper	352 - 1645	17.9	0.88
Iron	30,000 - 60,000	26.8	4.0
Lead	706 - 11, 470	78.6	5.0
Manganese	560 - 1090	---	2.5
Nickel	55 - 86	---	11.0
Zinc	1180 - 4780	10.2	0.25

* For X-ray the detection limit is assumed to be 10 cps above blank in a 10% mixture of the sample in borax. For atomic absorption the lowest acceptable absorbance is 0.007 (98.5% T) in a 4% ash solution.

TABLE 3-17

Comparison of Results of Analysis by Atomic Absorption and X-Ray Fluorescence

Element	Ratio: $\frac{\text{ppm by X-Ray}}{\text{ppm by Atomic Absorption}}$
Copper	0.88 ± 0.16 (18%)
Iron	0.83 ± 0.15 (18%)
Lead	1.14 ± 0.25 (22%)
Zinc	0.67 ± 0.12 (18%)

TABLE 3-18

Relative Standard Deviation of Residue Samples (in %)

	Atomic Absorption		X-Ray	
Element	Standards	Samples	Standards	Samples
Copper	10.4	11.3	11.7	15.5
Iron	2.5	18.4	3.5	15.4
Lead	6.0	9.8	17.9	20.7
Zinc	0.6	13.0	6.8	12.3

using the method of sample preparation and analysis outlined in Appendix 3-I.

In summary, it appears that x-ray fluorescence may be used with satisfactory results only for the determination of copper, iron, and lead in incinerator residue. Atomic absorption is applicable to the determination of all trace metals listed, but with modifications to reduce or eliminate the effect of interferences.

2. Results and Interpretation

Results of analysis of Boston incinerator residues 1 through 6 are shown in Table 3-20. Results were obtained by atomic absorption, except for phosphates which were analyzed by a spectrophotometric procedure (Appendix 3-IV).

Cadmium, chromium, cobalt, and nickel are all present in concentrations of less than 100 parts per million. Iron is present in the percent range expected (3 to 4 1/2%). Zinc and lead have median values of about 0.4%, while manganese and copper range from about 0.1% downward. All show a variability from one sample to another so that ranges of concentration rather than averages must be used. A rough correlation appears to exist between the iron and manganese content of the samples; however ratios of other metals were completely random. Soluble ions rapidly dissolved or leached from incinerator residues immersed in sea water over long periods may be useful (e.g., nitrates and phosphates), harmful (e.g., sulfides), or inconsequential

TABLE 3-19

Comparison of Results of Residue Analysis by Two Laboratories

Parts per Million

Metal	Rhode Island AA	Harvard AA	 X-Ray
Cadmium	32	12	---
Cobalt	957	17	---
Chromium	3457	<10	---
Copper	1155	1295	791
Iron	46,800	45,000	39,200
Manganese	131	690	---
Nickel	1410	68	---
Lead	6740	3570	5360
Zinc	11,530	7410	4780

(Boston incinerator Residue #4 collected 5/3/66) (e.g., chlorides and sulfates). Phosphate ion is of particular interest as phosphorus is usually the limiting element in sea water during the critical spring and early summer reproduction and growth phases in northern waters. Because of the difficulties associated with measuring small changes of common ions in sea water, the phosphate solubility tests were conducted with distilled water. Results with sea water would be different, but not greatly so, for the ions measured. Some of the tests were intended to measure the maximum ion release under conditions of prolonged imersion and, for these, acid extraction was employed. From Table 3-20, it may be seen that the amount of water soluble phosphate ion rapidly extracted from incinerator residues in water represents about 3 ppm whereas the total acid extractable phosphate amounts to more than 9000 ppm, based on the total weight of the under 1/2-inch fraction of the Boston Municipal Incinerator residue. These values suggest that phosphate additions to sea water from incinerator residues could become valuable stimulants to marine growth other things being unchanged.

These figures represent the entire acid-soluble content of the residues and must be interpreted in that light. In contrast to acid, sea water will leach out the metals very slowly and will provide a tremendous dilution. The sample is not representative of whole residue as it is composed of that portion less than 1/2 inch diameter. From Section 3-I, this represents an average of 45% of the total residue from the Boston incinerator.

TABLE 3-20

PARTS PER MILLION TRACE METALS IN BOSTON INCINERATOR RESIDUE

Sample	Date	% Residue on ignition	Cd	Cr	Co	Cu
1	11-26-65	90.90	9.9	<10	16.5	524
2	11- 2-65	91.10	12.3	41	20.5	371
3	1- 5-66	85.38	11.0	<10	14.0	860
4	5- 3-66	93.70	12.0	<10	17.0	1295
5	7-27-66	97.72	16.0	<10	25.0	587
6	11- 7-66	91.78	9.1	44	33.0	820

Sample	Fe	Pb	Mn	Ni	PO_4^{-3} H_2O Sol.	PO_4^{-3} Total	Zn
1	37950	706	585	54	3.0	5300	2404
2	42900	4580	813	80	0.8	3930	4619
3	41500	9700	757	62	13.8	13980	5975
4	45000	3570	690	68	<0.8	9790	7408
5	48500	3920	1076	59	1.3	12560	3962
6	48500	2100	560	86	0.8	9120	5900

AVERAGE CONCENTRATIONS (ppm)

Cadmium	11.7	±	2.4
Chromium	<20.8	±	16.8
Cobalt	21.0	±	7.0
Copper	743.0	±	327.0
Iron	44,058.0	±	4136.0
Lead	4096.0	±	3078.0
Manganese	747.0	±	188.0
Nickel	68.2	±	12.5
Phosphates (water soluble)	3.3	±	5.3
Phosphates (total)	9100.0	±	3900.0
Zinc	5045.0	±	
Residue on ignition	91.8	±	4.0%

Cans make up an average of 18% of total residue. They have an extremely high iron content as well as small amounts of other metals used in solder which would be dissolved slowly by sea water. The type of waste, method of incineration, and completeness of combustion affect the concentration of trace metals. The insoluble portion of the residue is composed chiefly of oxides and silicates of aluminum, titanium, and calcium.

As an indication of the rate of solution, two concentrations of Boston incinerator residue were prepared. A synthetic sea water was used as the solvent. This was made in our own laboratories according to a formula proposed by Lyman and Fleming(9) (Appendix 3-III). It is based on a chlorinity of 19% which is equivalent to a salinity of 34.3%.In Table 3-21 the concentration of the added ions in the solution is compared with that of a solution of "Instant Ocean", a proprietary product (Aquarium Systems, Inc., Wickliffe, Ohio), and a sea water of 34% salinity as reported by Riley and Skirrow.(10) According to the latter authors, 97% of sea water has a salinity of 33-37% or a chlorinity of 18.3-20.5%. Also shown are the major ions in a standard sea water adopted by the International Association of Physical Oceanography based on 35% salinity.

Table 3-22 shows the concentration (in parts per million) of trace metals in solution resulting from 5% and 25% suspensions of

TABLE 3-21

Synthetic Sea Water

Concentration of major ions in solution

	"Instant Ocean" g/1	34% Salinity Riley & Skirrow g/kg	Lyman & Fleming g/1
Na	10.3	10.452	9.919
Mg	2.62	1.257	1.272
Ca	0.47	0.401	0.398
K	0.37	0.376	0.381
Sr	0.06	0.008	0.013
B	--	0.004	0.005
Cl	20.76	18.801	19.00
SO_4	5.2	2.634	2.65
Br	--	0.065	0.064
F	--	0.0013	0.0014
HCO_3	--	0.138	0.140
Salinity	37.5%	34.0%	34.3%

International Association of Physical Oceanography standard sea water:

Chlorinity = 19.373 parts/thousand (35.0% salinity)

Mg = 1.30 g/1	K = 0.379 g/1
Ca = 0.409 g/1	Na = 10.8 g/1

TABLE 3-22

P.P.M. TRACE METALS IN SOLUTION FROM 5% AND 25% SUSPENSIONS OF BOSTON INCINERATOR RESIDUE IN SYNTHETIC SEA WATER

	Cd		Cr	Co		Cu		Fe		Pb		Mn	Ni	Zn	
	1	10	1 or 10	1	10	1	10	1	10	1	10	1 or 10	1 or 10	1	10
1- 5	<0.01	<0.01	<0.3	<0.15	<0.15	<0.042	<0.042	<0.22	<0.22	<0.22	<0.22	<0.10	<0.3	0.20	<0.016
1- 5-G	"	"	"	0.39	"	"	"	"	"	"	"	"	"	0.033	"
1-25	"	"	"	<0.15	"	"	"	"	"	"	"	"	"	0.21	0.067
1-25-G	"	"	"	0.41	"	0.123	"	"	"	0.47	"	"	"	0.59	0.115
2- 5	<0.01	<0.01	<0.3	<0.15	<0.15	<0.042	<0.042	<0.22	<0.22	<0.22	<0.22	<0.10	<0.3	0.070	<0.016
2- 5-G	"	"	"	0.32	"	"	"	"	"	"	"	"	"	0.150	0.085
2-25	"	"	"	<0.15	"	"	"	"	"	"	"	"	"	0.37	0.020
2-25-G	"	"	"	0.21	"	"	"	"	"	0.31	"	"	"	0.094	<0.016
3- 5	<0.01	0.011	<0.3	<0.15	<0.15	<0.042	0.048	<0.22	<0.22	0.25	<0.22	<0.10	<0.3	0.029	<0.016
3- 5-G	"	<0.01	"	"	"	0.048	<0.042	"	0.22	0.27	"	"	"	0.245	0.016
3-25	"	0.020	"	0.36	"	0.128	"	"	0.28	0.62	"	"	"	0.50	0.042
3-25-G	"	0.010	"	0.67	"	0.055	"	"	<0.22	<0.22	"	"	"	0.225	<0.016
4- 5	<0.01	<0.01	<0.3	<0.15	<0.15	<0.042	<0.042	<0.22	<0.22	<0.22	<0.22	<0.10	<0.3	0.125	<0.016
4- 5-G	"	"	"	0.39	"	"	"	"	"	0.22	"	"	"	0.170	"
4-25	"	0.013	"	0.21	"	"	0.124	"	"	<0.22	"	"	"	0.190	0.0235
4-25-G	"	<0.01	"	0.36	"	0.070	0.082	"	0.28	"	"	"	"	0.080	0.0400
5- 5	<0.01	0.014	<0.3	0.21	<0.15	<0.042	<0.042	<0.22	<0.22	<0.22	<0.22	<0.10	<0.3	0.060	0.013
5- 5-G	"	0.013	"	0.43	"	"	0.075	"	"	"	"	"	"	0.023	0.013
5-25-G	"	<0.01	"	0.52	"	0.055	0.24	"	0.25	0.31	"	"	"	0.24	0.140

Boston incinerator residues in synthetic sea water after one and ten days, while Table3-23presents the same data expressed as percent of the original metal content of the residue which has dissolved. The effect of adding a wetting agent is also demonstrated here. The letter "G" following a sample number indicates that 1 ml of 1% GAFAC (RE610 - General Aniline and Film Corp.) per gram of ash has been added to the suspension. Visual inspection indicates a significant wetting effect. Very little floating material is observed, while in untreated mixtures, an apparently significant portion of residue remains on the surface or suspended in the water.

Concentrations of chromium, manganese, and nickel were below the limits of detection by atomic absorption, while many of the others approach or are below these limits (refer to Table 3-16). With this in mind, several tentative conclusions may be reached. Cadmium and iron appear to increase in solubility with time, whereas cobalt, lead, and zinc show a slight decrease. Cadmium appears to be less soluble in the presence of Gafac, but cobalt is signigicantly more so. The 25% residue suspension does not appear to produce a higher concentration of trace metals in solution than the 5% suspension.

According to results in Section3-I, an average of 2.7% of minus 18 mesh Boston incinerator residue is soluble in distilled water when mixed in a 5% suspension and let stand for a minimum of 12 hours. No figures are given for solubility of Boston residue in sea water; however from results obtained on Dedham

TABLE 3-23

% OF METAL CONTENT OF INCINERATOR RESIDUE
SOLUBLE IN SYNTHETIC SEA WATER

Sample	Cd		Cr	Co		Cu		Fe		Pb		Mn	Ni	Zn	
	1	10	1 or 10	1	10	1	10	1	10	1	10	1 or 10	1 or 10	1	10
1- 5	<2.02	<2.02	---	<18.2	<18.2	<0.160	<0.160	<0.016	<0.016	<0.63	<0.63	<0.343	<11.06	0.167	<0.0133
1- 5-G	"	"	---	47.3	"	"	"	"	"	"	"	"	"	0.0275	"
1-25	<0.403	<0.403	---	<3.6	<3.6	<0.032	<0.032	<0.00232	<0.00232	<0.13	<0.13	<0.0712	< 2.21	0.0349	0.0111
1-25-G	"	"	---	9.95	"	0.094	"	"	"	0.27	"	"	"	0.0980	0.0191
2- 5	<1.63	<1.63	<14.6	14.6	<14.6	<0.226	<0.226	<0.0102	<0.0102	<0.92	<0.92	<0.246	<7.50	0.0303	<0.0069
2- 5-G	"	"	"	31.2	"	"	"	"	"	"	"	"	"	0.0650	0.0368
2-25	<0.325	<0.325	<2.91	<3.0	<3.0	<0.045	<0.045	<0.00205	<0.00205	<0.19	<0.19	<0.0493	<1.50	0.0321	0.0018
2-25-G	"	"	"	4.1	"	"	"	"	"	0.278	"	"	"	0.0081	<0.0014
3- 5	<1.82	2.09	---	---	---	<0.098	0.112	<0.0106	<0.0106	0.52	<0.45	<0.265	---	0.0106	<0.0056
3- 5-G	"	<1.82	---	---	---	0.112	<0.098	"	0.0106	0.55	"	"	---	0.0854	0.0056
3-25-	<0.364	0.746	---	---	---	0.059	<0.020	<0.00212	0.00270	0.26	<0.091	<0.053	---	0.0348	0.0029
3-25-G	"	0.364	---	---	---	0.026	"	"	<0.00212	<0.091	"	"	---	0.0156	<0.0011
4- 5	<1.67	<1.67	---	---	---	<0.065	<0.065	<0.00978	<0.00978	<0.123	<0.123	<0.290	---	0.0338	<0.0043
4- 5-G	"	"	---	---	---	"	"	"	"	0.123	"	"	---	0.0459	"
4-25	<0.333	0.433	---	---	---	<0.013	0.038	<0.00195	<0.00195	<0.025	<0.025	<0.058	---	0.0103	0.0013
4-25-G	"	<0.333	---	---	---	0.0216	0.0253	"	0.00249	"	"	"	---	0.0043	0.0022
5- 5	<1.25	1.81	<5.04	16.8	<12.0	<0.143	<0.143	<0.00908	<0.00908	<0.112	<0.112	<0.186	---	0.0303	<0.0081
5- 5-G	"	1.63	"	34.4	"	"	0.256	"	"	"	"	"	---	0.0119	"
5-25-G	<0.25	<0.25	<1.00	8.3	<2.4	0.0375	0.1635	<0.00181	<0.00206	0.031	<0.022	<0.037	---	0.0242	0.0141

$$\frac{(\mu g/ml \times ml)H_2O}{(g \times \mu g/g) \text{ original residue}} \times 100 = \% \text{ sol.}$$

and Waltham ash, solubility in fresh water is about 1.2 times greater than in salt. The major solutes are alkali metals, as evidenced by a rise in pH when residue is mixed with water. A 5% suspension of minus 18 mesh Boston residue raises the pH of salt water to 8.7 from a normal of 8.0, while in fresh water, the pH increases from less than 7 to over 9.0. Sea water is highly buffered which prevents the pH from changing greatly.

The solution of salts in sea water is a complex process. In some cases there may be initial solution followed by precipitation due to pH changes or the presence of dissolved gases. Little is known about the effect of high pressures, such as would be found at depths, on solubilities and chemical reactions. Some exchange takes place between electrolytes and clays or zeolites residing on the ocean floor. Marine organisms also concentrate metals and may release them back to the sea water in a different form through metabolic processes. It is known that there are chelating agents present in sea water which are of organic origin and which affect solubilities of various trace metals.

Through a year's cycle there is little variation in the chlorinity of sea water or of the major inorganic dissolved salts. Temperature, however, fluctuates from a low of about

5°C to a summer high of 18°C or over. Growth of plankton and other marine life is obviously affected by the seasons and this, in turn, changes the concentration of many organically bound elements such as carbon, phosphorous, and nitrogen.

C. Bottom Sediments

Samples of sediments were collected from pens where clams were exposed to incinerator residue from July to October 1966 (see Sect. 4). It was assumed that these samples would represent residue remaining after dumping operations. One sample was collected from the control plot (B), one from the edge of plot A which was treated with two pounds of whole residue twice weekly, and one from the center of plot C, which was treated with four pounds of whole residue twice weekly during the period.

For analysis, samples were dried at 110°C. A 4 gram aliquot was weighed, dissolved in the same manner as incinerator residue, and made up to 25 ml for analysis by atomic absorption.

Results, shown in Table 3-24, are reported in parts per million (micrograms per gram) in dried sample; net parts per million (assuming control plot B to be a blank); and as a ratio of total parts per million in exposed plot to control plot.

The net parts per million is indicative of the undissolved residue remaining in the treatment plots, and the ratio indicates the magnitude of the increase. It is difficult to draw any definite conclusions from these data, except that residue appears to have accumulated in the treatment plots as evidenced by an increase in the trace metals. A larger number of samples taken

TABLE 3-24
TRACE METALS IN BOTTOM SEDIMENTS

Metal	Sample	ppm in Dried Sample	Net ppm (Control Subtracted)	Ratio Exposed: Control
Cadmium	Control Plot B	5.20	--	--
	Edge Plot A	6.79	1.59	1.31
	Center Plot C	11.6	6.40	2.23
Chromium	Control	25.3	--	--
	Edge	24.5	neg.	0.969
	Center	34.0	8.7	1.34
Cobalt	Control	6.43	--	--
	Edge	7.67	1.24	1.19
	Center	9.89	3.46	1.54
Copper	Control	36.2	--	--
	Edge	130	94	3.59
	Center	648	612	17.9
Iron	Control	7,400	--	--
	Edge	11,900	4,500	1.61
	Center	11,700	4,300	1.58
Lead	Control	33.6	--	--
	Edge	373	339	11.1
	Center	1,260	1,226	37.5
Manganese	Control	142	--	--
	Edge	210	68	1.48
	Center	207	65	1.46
Nickel	Control	12.7	--	--
	Edge	15.3	2.6	1.20
	Center	21.2	8.5	1.67
Zinc	Control Plot	435	--	--
	Edge Plot	1,400	965	3.22
	Center Plot	336	neg.	0.773

before and after treatment, as well as more well-defined sampling in terms of area and depth, would be necessary to obtain more specific information.

D. Marine Organisms

1. Previous Studies

In conjunction with the bioassay tests conducted on various marine organisms, trace metal concentrations were determined in exposed and unexposed quahogs (Mercenaria mercenaria), winter flounder (Pseudopleuronectes americanus), and scallops (Pecten magellanicus). Unexposed animals and those exposed to various concentrations of incinerator were studied. The entire organisms as well as dissected parts were examined.

Published data on trace metal levels in marine organisms is scanty. A paper by Pringle et al (11) gives data on trace metals in various shellfish. Table 3-25 compares results on the northern quahog with those obtained in this laboratory. Values are comparable and within the same range for all elements except cobalt. The reason for this discrepancy is unknown.

In published literature, analysis of the composition of marine organisms has been largely confined to the determination of moisture, fat, and ash plus the alkali and alkaline earth metals which form the largest portion of the ash.

Table 3-26 taken from a paper by Sohn et al, (12) gives the proximate composition of several commercially important fish from New England waters. For these analyses, fish were divided into

TABLE 3-25

AVERAGE TRACE METAL LEVELS
IN NORTHERN QUAHOGS
(*Mercenaria mercenaria*)

[illegible]

	Cd	Cr	Co	Cu	Fe	Pb	Mn	Ni	Zn
Harvard	0.19±0.05	0.25*	1.14*	3.6±1.1	16.0±8.5	0.74*	1.9±1.4	0.59*	13.3±2.5
Pringle et al.	0.19	0.31	0.20	2.6	30	0.52	5.8	0.24	20.6
Range **(Pringle)**	0.10-0.73	0.19-5.80	0.10-0.20	1.0-16.5	9.0-83.0	0.10-7.5	0.7-29.7	0.10-2.4	11.5-40.2

* Single result of several pooled samples.

TABLE 3-26

PROXIMATE COMPOSITION OF NEW ENGLAND FISH

Table 3 - Proximate Composition of Fillets and Offal of Cod (Gadus morhua)

Season Captured	No. of Samples	Fillet Composition								Offal Composition							
		Protein (**)		Oil (**)		Ash (**)		Moisture (**)		Protein (**)		Oil (**)		Ash (**)		Moisture (**)	
		Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range
		(Percent)															
Spring	24	18.0	16.6-19.2	.09	.03-0.2	1.2	1.0-1.4	81.4	79.8-82.4	16.1	15.0-17.5	0.7	0.3-2.2	4.4	3.0-6.6	78.3	76.2-79.8
Summer . . .	12	17.4	16.6-18.4	.1	.03-0.2	1.0	0.9-1.1	81.5	80.4-82.4	1/	1/	1/	1/	1/	1/	1/	1/
Fall	12	18.1	17.8-18.4	.08	.06-.11	1.0	0.9-1.1	80.6	80.1-81.0	15.9	14.3-16.7	4.3	3.4-4.8	3.4	2.9-4.4	76.3	74.9-78.5
Winter. . . .	12	17.7	16.3-18.7	0.05	.03-.07	1.1	1.1-1.3	80.9	80.4-82.1	16.5	15.6-18.1	0.3	0.1-0.6	4.6	3.4-6.9	78.5	77.3-80.5

1/ These cod were received in the "gutted" condition.

**Variation related to the season at the 5-percent level of significance.

Table 4 - Proximate Composition of Fillets and Offal of Ocean Perch (Sebastes marinus)

Season Captured	No. of Samples	Fillet Composition								Offal Composition							
		Protein (***)		Oil (***)		Ash (***)		Moisture (***)		Protein (**)		Oil (***)		Ash (-)		Moisture (***)	
		Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range
		(Percent)															
Spring	36	18.1	17.0-19.4	1.4	0.2-4.1	1.1	1.0-1.8	79.3	75.9-82.0	16.2	14.9-17.9	8.5	1.0-12.9	6.7	4.8-9.3	68.3	62.8-78.4
Summer . . .	12	18.1	17.3-18.5	1.1	0.3-1.9	1/	1/	78.8	77.4-80.4	15.9	15.0-17.9	4.0	2.3-7.2	6.3	4.4-8.7	73.6	66.2-77.9
Fall	24	17.6	15.3-19.0	0.6	0.2-1.1	1.1	1.0-1.7	80.3	78.4-84.4	16.1	15.1-17.2	6.4	4.8-8.0	6.4	6.0-8.0	70.5	69.0-72.5
Winter. . . .	12	18.1	17.3-19.1	1.3	0.4-2.8	1.1	0.9-1.4	78.9	76.8-80.8	17.0	16.0-19.0	8.4	5.7-11.5	6.7	6.0-8.3	67.4	63.0-71.1

1/ Sample was lost.

(-) Variation is not related to the season.

(**) Variation related to the season at the 5-percent level of significance.

(***) Variation related to the season at the 1-percent level of significance.

Table 5 - Proximate Composition of Fillets1/ and Offal of Mackerel (Scomber scombrus)

Season Captured	No. of Samples	Fillet Composition								Offal Composition							
		Protein (***)		Oil (**)		Ash (***)		Moisture (***)		Protein (***)		Oil (***)		Ash (-)		Moisture (***)	
		Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range	Av.	Range
		(Percent)															
June	6	15.1	13.9-16.2	21.5	18.6-23.5	1.0	0.8-1.1	61.9	60.3-64.0	13.3	12.9-13.6	18.1	17.2-19.2	3.1	2.7-3.4	65.1	65.0-65.5
October . . .	6	18.1	16.4-18.5	23.1	19.3-28.7	1.4	0.9-1.7	57.0	56.2-57.5	15.0	14.2-16.2	19.4	16.0-20.2	3.6	2.9-4.1	61.6	60.1-67.3
November . .	6	18.7	18.2-19.4	14.9	10.4-20.3	2.0	1.1-2.2	64.3	59.4-68.4	15.7	14.1-16.4	15.5	13.5-17.4	3.9	3.1-4.4	65.2	63.0-67.4

1/ These fillets were analyzed with the skins on, since this is the way they usually are prepared.

(-) Variation is not related to the season.

(**) Variation related to the season at the 5-percent level of significance.

(***) Variation related to the season at the 1-percent level of significance.

edible (fillet) and inedible (offal) portions. It should be noted that all properties except offal ash of perch and mackerel are variable with the season.

In Table 3-27 Eisler(13) has reported the concentration of alkali and alkaline earth metals, iron, and zinc in whole quahog ash as well as in several tissues. (To express concentrations in parts per million, multiply Eisler's results by 1000.)

Vinogradov(14) is the most complete source of information concerning trace metals in marine organisms, although no data are included on the quahog. Data are given on the basis of percent of metal in living matter, dry matter, or ash. For comparison purposes, dry matter is 20-40% and ash about 3% of living matter. We have expressed results in most instances in parts per million for ease of comparison with our figures. Most of the information given by Vinogradov has been tabulated from a number of other sources, and it should be borne in mind that different methods or techniques of sample preparation or analysis could lead to different results.

Data on the winter flounder are confined to iodine, which is said to comprise 0.18 to 0.53 ppm of living tissue. In living matter of flounder (pleuronectes), 14.3 ppm of zinc was reported, 1.8 to 2.3 ppm copper, and 0.5 to 1.7 ppm arsenic. The largest amount of arsenic was found in the fat fraction of the liver and other organs. According to Monier-Williams,(15) oysters contain 3-10 ppm arsenic, lobsters up to 70 ppm, mussels up to 120 ppm, and

TABLE 3-27

Average concentration, in g/kg ash, of sodium, calcium, potassium, magnesium, zinc, and iron in whole animal and selected tissues of control quahog clams.

	Na	Ca	K	Mg	Zn	Fe	Total
Whole Clam	182.	46.6	125.	33.2	1.68	0.81	389.29
Whole Clam 1/	---	---	---	---	1.49	0.28	-----
Whole Clam 2/	---	---	---	---	0.69	1.49	-----
Mantle	198.	115.	83.9	34.9	0.81	0.74	433.35
Gills	211.	109.	147.	43.0	3.07	1.48	514.55
Muscle	146.	98.5	143.	32.3	1.50	0.80	422.10
Muscle 1/	140.	26.0	213.0	32.9	---	0.00	411.9
Remainder	166.	49.1	116.	35.7	2.14	0.76	369.70

1/ From Vinogradov (1953

2/ From Pringle (pers. comm.)

From: Eisler, R., "Changes in Metal Content of the Quahog Clam, *Mercenaria Mercenaria* after exposure to Insecticides", *Chesapeake Science*, 8:253, 1967.

prawns up to 170 ppm. (In incinerator operation, arsenic is believed lost to the atmosphere. According to work done at Drexel, it was not detectable in the residue samples they analyzed). About 0.2% chlorine is present in fresh mussels, and fluorine may be found in the skeleton. The teeth of salt water fish contain about ten times the fluorine found in teeth of fresh water fish.

A great deal of information is given on scallops, but only on pecten jacobaeus, fumatus, maximus, and varius. Although there may be species differences, these data are presented in tabular form in Table 3-28. Sulfur is present in larger amounts than phosphorus, but reported concentrations are believed unreliable due to losses during sample preparation. Bromine is said to occur in larger amounts than iodine, but no figures are given. Fluorine is confined primarily to the shell.

According to Rice,(16) scallops (Aequipecten irradians) concentrate ^{65}Zn more than five times as much as clams (Mercenaria mercenaria) even though living in the same environment. They also concentrate ^{54}Mn to a greater extent, mostly in the kidney which is not eaten by man. He indicated that fish obtaining ^{65}Zn from food, concentrate it to a greater extent than those obtaining it from water. It may be assumed that the radioactive elements follow the same paths as their stable counterparts.

The major portion of the trace metals occurs as inorganic

Table 3-28

Concentrations of Trace Elements in Scallops

Element	Concentration in Whole Animal			Organs of Concentration
	ppm in Living	ppm in Dried	ppm in Ash	
Boron	---	---	---	100-300 ppm in mantle
Cadmium	---	---	---	500-2000 ppm in dry liver
Chlorine	1000-2000	---	---	---
Cobalt	---	0.068	---	---
Copper	---	---	30-40	---
Iodine	---	800-5000	---	---
Iron	---	---	500-2000	Gills, liver, kidneys
Lead	---	---	200	---
Manganese	---	---	100-600	Kidney
Phosphorus	---	---	14-22%	---
Zinc	---	---	800-1600	Liver

Abstracted from: Vinogradov, A. P., "The Elementary Chemical Composition of Marine Organisms," Sears Foundation for Marine Research, New Haven, 1953.

compounds in the organism. Some portion may be tied into an organic moledule, however. Table 3-29, from Vinogradov, illustrates possible organic forms and the site of concentration.

2. Results of Current Studies

In the following pages results of analysis for trace metals have been tabulated according to species (or organ) and metal. A summary is included indicating the nature of the exposure and conclusions based on statistical analysis. The percent ash, or residue on ignition at 550°C is tabulated in the same manner in order to enable comparison with results of other investigators which may be expressed in terms of ash. In addition to the trace metals the presence of calcium, potassium, strontium, sodium, and bromine was confirmed in the ash from these organisms. The significance of these findings and descriptions of the exposure conditions for the marine organisms studied are contained in Section 4, Marine Biological Studies.

TABLE 3-29

METALLO-ORGANIC AND OTHER SPECIAL COMPOUNDS IN MARINE ORGANISMS

ELEMENT	Compounds
	A. Ordinary organic compounds containing elements in addition to carbon, hydrogen, and oxygen.
Nitrogen	In all proteins and in many other compounds in all classes of organisms.
Sulfur	As above.
Phosphorus	In nucleoproteids and other proteins and in various compounds of phosphoric acid; in organic matter in all classes.
Arsenic	Organic compounds soluble in fats; not thoroughly studied.
Silicon	?
	B. Halogenated organic compounds
Chlorine	Alcyonaria* and possibly sponges contain a chlorine compound analogous to di-iodotyrosin.
Bromine	Di-bromtyrosin in the Alcyonaria, Antipatharia and sponges; di-bromindigo in the Muricidae and bromo-organic compounds which have not been studied thoroughly in algae.
Iodine	Di-iodotyrosin in the Alcyonaria, Antipatharia and sponges; thyroxin in the thyroid gland of fish and other vertebrates.
	C. Compounds with alkaline earths
Magnesium	Chlorophyll in blue-green algae and all other seaweeds and higher plants; in some proteins.
Calcium	In some proteins; as salts of organic acids, and so forth, in all classes.
	D. Heavy metal compounds, mainly enzymes, or those involved in oxygen transport
Copper	In porphyrins, cuproporphyrin, uroporphyrin, and so forth; haemocuprin in the red blood of higher organisms; in oxidase (polyphenolase and others); turacin in the feathers of Musophagidae; haemocyanin in Mollusca, Crustacea, Arachnoidea and Xiphosura; in compounds with proteins in all classes, especially in glands, the liver, and so forth.
Zinc	In compounds with protein (not studied thoroughly), as in snake poison, in mushrooms, in many types of protein in the liver of lower and higher organisms; in blood as sycotypin, and so forth; in carbonic anhydrase in the blood of lower and higher organisms.
Manganese	In protein of the blood and liver of many Mollusca and Arthropoda; in arginase.
Iron	In the haemerythrin, chlorocruorin and erythrocruorin of lower organisms and in the haemoglobin of higher vertebrates; in many proteins of glandular organs of lower and higher organisms.
Cadmium	In the protein of *Pecten*.†H
Cobalt	In the protein of the liver of Mollusca.
Vanadium	In vanadin, a blood pigment in some Ascidiae.

* No authority is given; the published accounts of chlorine compounds relate to lichens and fungi.

†H The evidence that the cadmium in *Pecten* is combined with a protein is not given. The same is also true of cobalt in Mollusca.

From: Vinogradov, A.P., "The Elementary Chemical Composition of Marine Organisms," Sears Foundation for Marine Research, New Haven, 1953.

a. Trace Metal Concentrations in Whole Winter Flounder

1. Exposure group number 1 (1968)

Pseudopleuronectes americanus held in a 1% concentration of residue (less than $\frac{1}{2}$ inch screen size) for 34 days (August to September, 1968).

The average received weight of the 20 control fish was 19.37 ± 7.34 grams and of 20 treated fish was 21.14 ± 15.99 grams. Samples 18C, 19C, 12T, 16T, and 17T were all less than 4.0 grams, and were excluded from a second statistical analysis as immature. The immature fish could well have a different metabolic rate from adults, and should therefore be considered a separate population. The reasonableness of this assumption is indicated by the marked decrease in relative standard deviation in every case except two (control iron group and treated percent ash group).

Statistical analysis indicates that lead is the only metal significantly increased after treatment of fish with residue.

Table 3-30a

TRACE METAL CONCENTRATIONS IN WHOLE WINTER FLOUNDER: CADMIUM

	Number Analyzed	Number Below Sensitivity	ppm	±	σ	Percent $\sigma/\overline{X}$	Pooled Result	Critical Ratio
Control	20	0	0.103	±	0.031	30.0	---	---
Treated	20	0	0.121	±	0.077	63.4	---	0.97
Control	18[a]	0	0.095	±	0.021	21.5	---	---
Treated	17[b]	0	0.095	±	0.021	22.6	---	0

[a] Omit samples 18C and 19C

[b] Omit samples 12T, 16T, and 17T

TABLE 3-30b

TRACE METAL CONCENTRATIONS IN WHOLE WINTER FLOUNDER: CHROMIUM

	Number Analyzed	Number Below Sensitivity	ppm	±	σ	Percent $\sigma/\overline{X}$	Pooled Result	Critical Ratio
Control	20	6	<0.45	±	0.097	21.5	---	---
Treated	20	7	<0.96	±	1.31	136.5	---	---
Control	18[a]	4	<0.472	±	0.079	16.8	0.265	---
Treated	17[b]	4	<0.552	±	0.185	33.4	0.307	---
	27	0	0.49	±	0.14	27.9		

[a] Omit samples 18C and 19C

[b] Omit samples 12T, 16T, and 17T

TABLE 3-30c

TRACE METAL CONCENTRATIONS IN WHOLE WINTER FLOUNDER: COBALT

	Number Analyzed	Number Below Sensitivity	ppm	±	σ	Percent $\sigma/\overline{X}$	Pooled Result	Critical Ratio
Control	20	1	<0.984	±	0.275	27.9	---	---
Treated	20	1	<1.041	±	0.432	41.5	---	0.50
Control	18[a]	0	0.913	±	0.162	17.8	---	---
Treated	17[b]	0	0.906	±	0.148	16.4	---	0.13

[a] Omit samples 18C and 19C

[b] Omit samples 12T, 16T, and 17T

TABLE3-30d

TRACE METAL CONCENTRATIONS IN WHOLE WINTER FLOUNDER: IRON

	Number Analyzed	Number Below Sensitivity	ppm	±	σ	Percent $\sigma/\bar{X}$	Pooled Result	Critical Ratio
Control	20	0	6.404	±	5.25	82.0	---	---
Treated	20	0	11.31	±	14.59	129.0	---	1.42
Control	18[a]	0	6.33	±	5.49	86.7	---	---
Treated	17[b]	0	6.108	±	2.574	42.1	---	0.15

[a] Omit samples 18C and 19C

[b] Omit samples 12T, 16T, and 17T

TABLE 3-30e

TRACE METAL CONCENTRATIONS IN WHOLE WINTER FLOUNDER: LEAD

	Number Analyzed	Number Below Sensitivity	ppm ± σ	Percent $\sigma/\overline{X}$	Pooled Result	Critical Ratio
Control	20	2	<0.948 ± 0.942	99.5	---	---
Treated	20	0	1.752 ± 1.147	65.4	---	2.4
Control	18[a]	1	<0.702 ± 0.132	18.9		---
Treated	17[b]	0	1.415 ± 0.810	57.2		3.6

[a] Omit samples 18C and 19C

[b] Omit samples 12T, 16T, and 17T

TABLE 3-30 f

TRACE METAL CONCENTRATIONS IN WHOLE WINTER FLOUNDER: MANGANESE

	Number Analyzed	Number Below Sensitivity	ppm	±	σ	Percent $\sigma/\overline{X}$	Pooled Result	Critical Ratio
Control	20	0	0.878	$\pm$	0.462	52.6	---	---
Treated	20	0	1.278	$\pm$	1.703	133.2	---	1.01
Control	18[a]	0	0.781	$\pm$	0.365	46.7	---	---
Treated	17[b]	0	0.716	$\pm$	0.375	52.4	---	0.52

[a] Omit samples 18C and 19C

[b] Omit samples 12T, 16T, and 17T

TABLE 3-30 g

TRACE METAL CONCENTRATIONS IN WHOLE WINTER FLOUNDER: NICKEL

	Number Analyzed	Number Below Sensitivity	ppm	±	σ	Percent $\sigma/\overline{X}$	Pooled Result	Critical Ratio
Control	20	2	<1.50	±	1.26	84.2	---	---
Treated	20	4	<2.15	±	2.25	104.6	---	1.1
Control	18[a]	0	1.252	±	0.296	23.7	---	---
Treated	17[b]	1	<1.290	±	0.303	33.5	---	0.4

[a] Omit samples 18C and 19C

[b] Omit samples 12T, 16T, and 17T

TABLE 3-30 h

TRACE METAL CONCENTRATIONS IN WHOLE WINTER FLOUNDER: ZINC

	Number Analyzed	Number Below Sensitivity	ppm ± σ	Percent $\sigma/\overline{X}$	Pooled Result	Critical Ratio
Control	20	0	24.9 ± 5.09	20.4	---	---
Treated	20	0	28.6 ± 9.79	34.2	---	1.5
Control	18[a]	0	23.8 ± 3.71	15.6		---
Treated	17[b]	0	24.5 ± 3.96	16.2		0.55

[a] Omit samples 18C and 19C

[b] Omit samples 12T, 16T, and 17T

TABLE 3-30 1

TRACE METAL CONCENTRATIONS IN WHOLE WINTER FLOUNDER: %ASH

	Number Analyzed	Number Below Sensitivity	Average %	±	σ	Percent $\sigma/\overline{X}$	Pooled Result	Critical Ratio
Control	20	0	3.81	±	0.34	8.8	---	---
Treated	20	0	4.03	±	0.58	14.4	---	1.47
Control	18[a]	0	3.78	±	0.32	8.6	---	---
Treated	17[b]	0	3.89	±	0.63	16.2	---	0.64

[a] Omit samples 18C and 19C

[b] Omit samples 12T, 16T, and 17T

2. Exposure group number 2 (1969)

Pseudopleuronectes americanus exposed to a 1% residue concentration for five months ending in mid-February, 1969. Only eight out of 33 treated fish survived, possibly due to an infection which affected both groups.

The data are presented in the same manner as the first group (August-September, 1968). The first set of results includes all samples received, and the second omits all fish under 4 grams as immature. As before, this procedure generally results in a decrease in the relative standard deviation.

The only metal which is significantly increased statistically is lead.

TABLE 3-31a

TRACE METAL CONCENTRATIONS IN WHOLE WINTER FLOUNDER: CADMIUM

	Number Analyzed	Number Below Sensitivity	ppm	± σ	Percent $\sigma/\overline{X}$	Pooled Result	Critical Ratio
Control:	8	0	0.132	0.049	37.6	--	--
Treated:	8	0	0.115	0.050	43.6	--	0.7
Control:	6[a]	0	0.110	0.032	29.1	--	--
Treated:	6[b]	0	0.095	0.041	42.6	--	0.7

[a] Omit samples 16C and I8C

[b] Omit samples 14T and 16T

TABLE 3-31b

TRACE METAL CONCENTRATIONS IN WHOLE WINTER FLOUNDER: Chronium

	Number Analyzed	Number Below Sensitivity	ppm	± σ	Percent $\sigma/\overline{X}$	Pooled Result	Critical Ratio
Control:	8	0	1.60	1.64	103	--	--
Treated:	8	0	1.67	1.41	84.6	--	0.1
Control:	6[a]	0	0.897	0.180	20.1	--	--
Treated:	6[b]	0	0.995	0.460	46.2	--	0.5

[a] Omit samples 16C and 18C

[b] Omit samples 14T and 16T

TABLE 3-31c

TRACE METAL CONCENTRATIONS IN WHOLE WINTER FLOUNDER: Cobalt

	Number Analyzed	Number Below Sensitivity	ppm	± σ	Percent $\sigma/\overline{X}$	Pooled Result	Critical Ratio
Control:	8	0	1.11	0.292	26.3	--	--
Treated:	8	0	0.986	0.298	30.2	--	0.8
Control:	6[a]	0	1.00	0.215	21.4	--	--
Treated:	6[b]	0	0.92	0.323	35.0	--	0.5

[a] Omit samples 16C and 18C

[b] Omit samples 14T and 16T

TABLE 3-31d

TRACE METAL CONCENTRATIONS IN WHOLE WINTER FLOUNDER: Copper

	Number Analyzed	Number Below Sensitivity	ppm	± σ	Percent $\sigma/\overline{X}$	Pooled Result	Critical Ratio
Control:	8	0	0.955	0.336	35.2	--	--
Treated:	8	0	0.885	0.325	36.7	--	0.4
Control:	6[a]	0	0.795	0.185	23.3	--	--
Treated:	6[b]	0	0.733	0.191	26.1	--	0.6

[a] Omit samples 16C and 18C

[b] Omit samples 14T and 16T

TABLE 3-31 e

TRACE METAL CONCENTRATIONS IN WHOLE WINTER FLOUNDER: Iron

	Number Analyzed	Number Below Sensitivity	ppm ±	σ	Percent $\sigma/\overline{X}$	Pooled Result	Critical Ratio
Control:	8	0	4.59	1.75	38.1	--	--
Treated:	8	0	4.56	2.99	65.5	--	<0.1
Control:	6[a]	0	3.77	1.02	27.1	--	--
Treated:	6[b]	0	4.05	3.36	82.9	--	0.2

[a] Omit samples 16C and 18C

[b] Omit samples 14T and 16T

Table 3-31 f

TRACE METAL CONCENTRATIONS IN WHOLE WINTER FLOUNDER: Lead

	Number Analyzed	Number Below Sensitivity	ppm ±	σ	Percent $\sigma/\overline{X}$	Pooled Result	Critical Ratio
Control:	8	0	1.25	0.61	48.4	--	--
Treated:	8	0	1.53	0.54	35.7	--	1.0
Control:	6[a]	0	0.970	0.175	18.0	--	--
Treated:	6[b]	0	1.49	0.574	38.4	--	2.1

[a] Omit samples 16C and 18C

[b] Omit samples 14T and 16T

TABLE 3-31g

TRACE METAL CONCENTRATIONS IN WHOLE WINTER FLOUNDER: Manganese

	Number Analyzed	Number Below Sensitivity	ppm ±	σ	Percent σ/$\overline{X}$	Pooled Result	Critical Ratio
Control:	8	0	0.831	0.260	31.3	--	--
Treated:	8	0	0.900	0.320	35.6	--	0.5
Control:	6[a]	0	0.710	0.141	19.8	--	--
Treated:	6[b]	0	0.798	0.305	38.2	--	0.6

[a] Omit samples 16C and 18C

[b] Omit samples 14T and 16T

TABLE 3-31h

TRACE METAL CONCENTRATIONS IN WHOLE WINTER FLOUNDER: Nickel

	Number Analyzed	Number Below Sensitivity	ppm	± σ	Percent σ/$\overline{X}$	Pooled Result	Critical Ratio
Control:	8	2	<2.52	1.21	47.9	2.67	--
Treated:	8	2	<2.53	1.54	60.7	1.77	0
Control:	6[a]	0	1.99	0.366	18.4	--	--
Treated:	6[b]	0	1.93	0.991	51.4	--	0.1

[a] Omit samples 16C and 18C

[b] Omit samples 14T and 16T

TABLE 3-311

TRACE METAL CONCENTRATIONS IN WHOLE WINTER FLOUNDER: Zinc

	Number Analyzed	Number Below Sensitivity	ppm	± σ	Percent $\sigma/\overline{X}$	Pooled Result	Critical Ratio
Control:	8	0	25.4	11.7	46.2	--	--
Treated:	8	0	20.3	9.95	48.9	--	0.9
Control:	6[a]	0	20.6	6.03	29.3	--	--
Treated:	6[b]	0	16.3	7.04	43.2	--	1.1

[a] Omit samples 16C and 18C

[b] Omit samples 14T and 16T

TABLE 3-31J

TRACE METAL CONCENTRATIONS IN WHOLE WINTER FLOUNDER: % ASH

	Number Analyzed	Number Below Sensitivity	Average %	± σ	Percent $\sigma/\overline{X}$	Pooled Result	Critical Ratio
Control:	8	--	4.06	0.779	19.2	--	--
Treated:	8	--	3.74	0.557	14.9	--	0.9
Control:	6[a]	--	3.73	0.428	11.5	--	--
Treated:	6[b]	--	3.66	0.620	16.9	--	0.2

[a] Omit samples 16C and 18C

[b] Omit samples 14T and 16T

b. Trace Metal Concentrations in Fish Parts

Pseudopleuronectes americanus were exposed in pens to incinerator residue during the period April 1966 to January 1967. "Low exposure" denotes treatment with two pounds of residue twice weekly, high exposure denotes treatment with four pounds of residue twice weekly.

Statistical analysis indicates that copper, lead, nickel, and zinc are concentrated by bone; chromium and nickel by muscle. Manganese may also concentrate in muscle, although this is uncertain, as several results are below the levels of analytical sensitivity and no pooled results were available. All chromium values were below the level of detection even in pooled samples except for control gut (0.64 ppm) and muscle exposed to high ash concentration (0.23 ppm).

TABLE 3-32a

TRACE METAL CONCENTRATIONS IN FISH PARTS: CADMIUM
(NINE MONTHS EXPOSURE TO INCINERATOR RESIDUE)

	Number Analyzed	Number below Sensitivity	ppm ± σ		Percent σ/X̄	Pooled Result	Critical Ratio
BONE							
Controls	9	0	.127 ±	0.0428	33.7	--	--
Low Exposure	4	0	.129 ±	0.0337	26.3	--	0.0918
High Exposure	5	0	.133 ±	0.0245	18.4	--	0.335
GILLS							
Controls	10	7	<.218 ±	0.0791	36.2	0.138	--
Low Exposure	4	0	.197 ±	0.0229	11.6	--	0.76
High Exposure	4	3	<.159 ±	0.0211	13.3	0.634	1.5
GUT							
Controls	10	6	<.125 ±	0.0502	40.2	0.131	--
Low Exposure	4	2	<.159 ±	0.0633	39.9	--	0.96
High Exposure	5	3	<.186 ±	0.1255	67.6	0.177	1.0
LIVER							
Controls	6	5	<.33 ±	0.140	42.4	--	--
Low Exposure	4	2	<.28 ±	0.0956	34.2	0.192	0.67
High Exposure	1	0	.123 ±	--	--	--	--
MUSCLE							
Controls	8	0	.0236 ±	0.0113	49.6	--	--
Low Exposure	3	0	.035 ±	0.0222	62.9	--	0.79
High Exposure	5	1	<.0312 ±	0.0220	70.4	--	0.64
OVARY							
Controls	4	0	.253 ±	0.169	66.6	--	--
Low Exposure	1	0	<.021 ±	--	--	--	--
High Exposure	2	0	<.429 ±	0.567	132.0	--	0.42
SKIN							
Controls	10	0	.0893 ±	0.0324	36.3	--	--
Low Exposure	3	0	.109 ±	0.0395	33.7	--	0.85
High Exposure	4	0	.111 ±	0.0336	48.4	--	0.76
TESTES							
Controls	4	3	<.930 ±	1.59	171.0	--	--
Low Exposure	3	3	<.062 ±	0.0336	54.3	--	1.09

TABLE 3-32b

TRACE METAL CONCENTRATIONS IN FISH PARTS: COBALT

(NINE MONTHS EXPOSURE TO INCINERATOR RESIDUE)

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent σ/$\overline{X}$	Pooled Result	Critical Ratio
BONE						
Controls	8	0	0.786 ± 0.094	12.0	--	--
Low Exposure	4	0	0.824 ± 0.375	45.5	--	0.20
High Exposure	5	0	0.893 ± 0.183	20.5	--	1.2
GILLS						
Controls	10	9	<1.80 ± 0.666	36.9	1.47	--
Low Exposure	4	4	<1.54 ± 0.513	33.2	--	0.78
High Exposure	4	4	<1.55 ± 0.346	22.4	1.47	0.39
GUT						
Controls	10	10	<1.02 ± 0.481	47.4	1.12	--
Low Exposure	4	4	<1.36 ± 0.976	71.5	--	0.67
High Exposure	5	5	<1.09 ± 0.553	50.9	0.85	0.24
LIVER						
Controls	6	6	<2.46 ± 1.47	59.8	--	--
Low Exposure	4	4	<2.13 ± 1.42	66.8	<0.35	0.36
High Exposure	1	1	<3.4 ± --	--	--	--
JSCLE						
Controls	8	0	0.256 ± 0.0639	25.0	--	--
Low Exposure	3	0	0.304 ± 0.0675	22.2	--	1.06
High Exposure	5	1	<0.305 ± 0.1043	34.2	--	0.94
OVARY						
Controls	4	3	<2.32 ± 1.50	64.9	--	--
Low Exposure	1	-	<2.3 ± --	--	--	--
High Exposure	2	1	<3.5 ± 4.78	136.0	--	0.34
SKIN						
Controls	10	0	0.614 ± 0.102	16.6	--	--
Low Exposure	3	0	0.574 ± 0.0927	16.2	--	0.64
High Exposure	5	0	0.502 ± 0.1895	37.8	--	1.2
TESTES						
Controls	4	4	<2.47 ± 2.70	109.2	--	--
Low Exposure	3	3	<0.54 ± 0.27	49.7	--	1.4

TABLE 3-32c

TRACE METAL CONCENTRATIONS IN FISH PARTS: Copper
(NINE MONTHS EXPOSURE TO INCINERATOR RESIDUE)

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent $\sigma/\overline{X}$	Pooled Result	Critical Ratio
BONE						
Controls	9	0	0.554 ± 0.211	38.1	--	--
Low Exposure	4	0	0.822 ± 0.691	84.0	--	0.76
High Exposure	5	0	1.153 ± 0.359	31.1	--	3.4
GILLS						
Controls	10	0	1.22 ± 0.467	38.2	--	--
Low Exposure	3	0	1.51 ± 0.38	25.5	--	1.09
High Exposure	4	0	1.13 ± 0.566	49.8	--	0.21
GUT						
Controls	10	0	1.33 ± 0.949	71.5	--	--
Low Exposure	4	1	<1.52 ± 0.957	63.1	--	0.34
High Exposure	4	0	1.24 ± 0.371	30.0	--	0.26
LIVER						
Controls	6	0	1.71 ± 0.638	37.4	--	--
Low Exposure	4	0	2.48 ± 1.816	73.3	--	0.81
High Exposure	1	0	9.19 ± --	--	--	--
MUSCLE						
Controls	8	0	0.282 ± 0.245	86.9	--	--
Low Exposure	3	1	<0.177 ± 0.119	67.1	--	0.95
High Exposure	5	0	0.359 ± 0.279	77.9	--	0.51
OVARY						
Controls	4	0	2.17 ± 1.48	68.4	--	--
Low Exposure	1	0	0.705 ± --	--	--	--
High Exposure	2	1	<1.03 ± 1.09	106.7	--	1.06
SKIN						
Controls	10	0	0.742 ± 0.238	32.1	--	--
Low Exposure	3	0	0.696 ± 0.1532	22.0	--	0.40
High Exposure	5	0	0.954 ± 0.4463	46.8	--	0.99
TESTES						
Controls	4	1	<0.608 ± 0.607	99.8	--	--
Low Exposure	3	0	0.806 ± 0.313	38.9	--	0.56

TABLE 3-32d

TRACE METAL CONCENTRATIONS IN FISH PARTS: IRON
(NINE MONTHS EXPOSURE TO INCINERATOR RESIDUE)

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent σ/X̄	Pooled Result	Critical Ratio
BONE						
Controls	9	0	19.8 ± 9.08	45.8	--	--
Low Exposure	4	0	12.0 ± 7.53	62.6	--	1.6
High Exposure	5	0	13.5 ± 3.77	27.8	--	1.8
GILLS						
Controls	10	0	23.7 ± 13 3	56.2	--	--
Low Exposure	4	0	18.3 ± 4.06	22.2	--	1.2
High Exposure	4	0	20.6 ± 9.11	44.2	--	0.50
GUT						
Controls	10	0	18.5 ± 9.27	50.1	--	--
Low Exposure	2	0	4.95± 4.96	100.3	--	3.0
High Exposure	5	0	17.29± 9.40	54.4	--	0.24
LIVER						
Controls	6	0	63.3 ± 54.1	85.5	--	--
Low Exposure	4	0	40.9 ± 12.2	29.9	--	0.98
High Exposure	1	0	10.8 ± --	--	--	--
MUSCLE						
Controls	8	0	2.81± 1.51	53.7	--	--
Low Exposure	2	0	2.55± 1.16	45.5	--	0.27
High Exposure	5	0	2.92± 1.21	41.4	--	0.14
OVARY						
Controls	4	2	<6.65± 6.89	104.0	--	--
Low Exposure	1	0	0.78± --	--	--	--
High Exposure	2	1	<4.57± 3 30	72.1	--	0.50
SKIN						
Controls	10	0	11.95± 6.33	53.0	--	--
Low Exposure	3	0	11.09± 9.92	89.4	--	0.14
High Exposure	5	0	7.12± 2.02	28.4	--	2.2
TESTES						
Controls	4	1	<3.42± 1.37	40.0	--	--
Low Exposure	3	0	1.97± 0.527	26.8	--	1.9

TABLE 3-32e

TRACE METAL CONCENTRATIONS IN FISH PARTS: LEAD

(NINE MONTHS EXPOSURE TO INCINERATOR RESIDUE)

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent σ/X̄	Pooled Result	Critical Ratio
BONE						
Controls	8	0	1.20 ± 0.270	22.4	--	--
Low Exposure	4	0	1.17 ± 0.568	48.4	--	0.10
High Exposure	5	0	1.70 ± 0.320	18.8	--	2.9
GILLS						
Controls	10	4	<3.26 ± 1.71	52.5	3.64	--
Low Exposure	4	0	3.43 ± 1.44	42.0	--	0.19
High Exposure	4	1	<2.52 ± 0.974	38.6	4.09	1.02
GUT						
Controls	10	4	<1.99 ± 0.854	42.9	3.01	--
Low Exposure	3	1	<2.21 ± 0.516	23.3	--	0.55
High Exposure	5	1	<2.17 ± 0.570	26.2	6.67	0.48
LIVER						
Controls	6	5	<3.42 ± 2.11	61.9	--	--
Low Exposure	4	1	<4.57 ± 2.83	62.0	1.69	0.69
High Exposure	1	0	1.77 ± --	--	--	--
MUSCLE						
Controls	6	0	0.315 ± 0.123	39.1	--	--
Low Exposure	2	0	2.32 ± 2.19	94.6	--	1.29
High Exposure	5	0	0.351 ± 0.0428	12.2	--	0.67
OVARY						
Controls	4	3	<3.70 ± 1.18	31.9	--	--
Low Exposure	1	0	0.767 ± --	--	--	--
High Exposure	2	1	<6.2 ± 8.20	132.2	--	0.43
SKIN						
Controls	10	0	1.19 ± 0.3832	32.2	--	--
Low Exposure	3	0	1.12 ± 0.0853	7.6	--	0.54
High Exposure	5	0	1.76 ± 0.6855	38.9	--	1.73
TESTES						
Controls	4	3	<2.62 ± 2.09	79.8	--	--
Low Exposure	3	1	<0.98 ± 0.451	46.0	--	1.52

TABLE 3-32f

TRACE METAL CONCENTRATIONS IN FISH PARTS: MANGANESE
(NINE MONTHS EXPOSURE TO INCINERATOR RESIDUE)

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent σ/X̄	Pooled Result	Critical Ratio
BONE						
Controls	9	0	1.58 ± 0.693	43.9	--	--
Low Exposure	4	0	1.05 ± 0.4082	38.9	--	1.7
High Exposure	4	0	1.46 ± 0.2973	20.4	--	0.44
GILLS						
Controls	10	0	1.70 ± 0.4190	24.6	--	--
Low Exposure	4	0	1.19 ± 0.097	8.11	--	3.8
High Exposure	4	0	1.296 ± 0.4132	31.9	--	1.6
GUT						
Controls	10	8	<0.526 ± 0.2213	42.1	--	--
Low Exposure	4	4	<0.705 ± 0.5003	71.0	--	0.69
High Exposure	5	3	<0.585 ± 0.27	46.6	--	0.42
LIVER						
Controls	6	6	<1.24 ± 0.728	59.2	0.58	--
Low Exposure	4	4	<1.08 ± 0.691	63.5	0.21	0.35
High Exposure	1	1	<0.55 ± --	--	--	--
'SCLE						
Controls	8	3	<0.069 ± 0.0218	31.6	--	--
Low Exposure	3	2	<0.072 ± 0.0147	20.5	--	0.26
High Exposure	5	2	<0.0960± 0.0186	19.4	--	2.39
OVARY						
Controls	4	3	<1.20 ± 0.716	59.7	--	--
Low Exposure	1	0	0.296 ± --	--	--	--
High Exposure	2	1	<2.75 ± 1.344	48.9	--	1.5
SKIN						
Controls	10	0	0.691 ± 0.229	33.1	--	--
Low Exposure	4	0	0.487 ± 0.069	14.2	--	2.55
High Exposure	5	0	0.522 ± 0.2010	38.5	--	1.5
TESTES						
Controls	4	4	<0.525 ± 0.520	99.1	--	--
Low Exposure	3	3	<0.290 ± 0.140	48.3	--	0.86

TABLE 3-32g

TRACE METAL CONCENTRATIONS IN FISH PARTS: NICKEL

(NINE MONTHS EXPOSURE TO INCINERATOR RESIDUE)

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent $\sigma/\overline{X}$	Pooled Result	Critical Ratio
BONE						
Controls	8	3	<1.726 ± 0.502	29.1	--	--
Low Exposure	4	2	<1.40 ± 1.01	72.2	--	0.61
High Exposure	5	0	2.10 ± 0.1201	5.7	2.46	2.02
GILLS						
Controls	10	10	<7.28 ± 2.79	38.3	1.80	--
Low Exposure	4	4	<6.20 ± 2.11	34.0	--	0.79
High Exposure	4	4	<6.22 ± 1.50	24.1	<1.80	0.92
GUT						
Controls	10	10	<3.91 ± 2.00	51.2	1.15	--
Low Exposure	4	4	<5.48 ± 4.00	73.0	--	0.75
High Exposure	5	5	<4.62 ± 2.11	45.6	<0.85	0.63
LIVER						
Controls	6	6	<10.12 ± 5.53	54.6	<0.72	--
Low Exposure	4	4	<7.68 ± 5.48	71.3	--	0.69
High Exposure	1	1	<4.1 ± --	--	--	--
MUSCLE						
Controls	8	8	<0.534 ± 0.127	24.3	<0.13	--
Low Exposure	3	3	<0.510 ± 0.1952	38.3	--	0.20
High Exposure	5	5	<0.724 ± 0.174	24.1	0.41	2.10
OVARY						
Controls	4	3	<8.82 ± 5.61	63.6	--	--
Low Exposure	1	1	<9.2 ± --	--	--	--
High Exposure	2	2	<13.8 ±18.70	136.0	--	0.37
SKIN						
Controls	10	9	<1.698 ± 0.768	45.2	1.03	--
Low Exposure	3	1	<1.273 ± 0.200	15.7	--	1.6
High Exposure	5	5	<1.324 ± 0.298	22.5	0.78	1.3
TESTES						
Controls	4	4	<4.08 ± 3.97	97.5	--	--
Low Exposure	3	3	<2.22 ± 1.03	46.3	--	0.90

TABLE 3-32h

TRACE METAL CONCENTRATIONS IN FISH PARTS: ZINC
(NINE MONTHS EXPOSURE TO INCINERATOR RESIDUE)

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent σ/X̄	Pooled Result	Critical Ratio
BONE						
Controls	8	0	15.94 ± 3.40	21.3	--	--
Low Exposure	4	0	14.86 ± 7.92	53.3	--	0.38
High Exposure	5	0	21.28 ± 2.72	12.8	--	3.12
GILLS						
Controls	10	0	21.9 ± 7.50	34.3	--	--
Low Exposure	4	0	21.4 ±15.8	73.7	--	0.05
High Exposure	4	0	19.2 ± 9.01	47.0	--	0.69
GUT						
Controls	10	0	8.84 ± 2.28	25.8	--	--
Low Exposure	4	0	9.38 ± 4.41	47.0	--	0.23
High Exposure	5	0	8.02 ± 3.27	40.7	--	0.50
LIVER						
Controls	6	0	13.08 ± 5.23	40.0	--	--
Low Exposure	4	0	12.34 ± 6.45	52.3	--	0.19
High Exposure	1	0	4.22 ± --	--	--	--
MUSCLE						
Controls	8	0	3.50 ± 2.54	72.5	--	--
Low Exposure	3	0	4.99 ± 3.33	66.8	--	0.70
High Exposure	5	0	4.50 ± 2.95	65.5	--	0.63
OVARY						
Controls	4	0	72.3 ±43.00	59.5	--	--
Low Exposure	1	0	16.7 ± --	--	--	--
High Exposure	2	0	26.02 ± 5.76	22.1	--	2.11
SKIN						
Controls	10	0	27.37 ±12.8	46.6	--	--
Low Exposure	3	0	34.4 ±21.4	62.0	--	0.54
High Exposure	5	0	26.2 ± 6.50	24.8	--	0.24
TESTES						
Controls	4	0	5.42 ± 3.42	63.1	--	--
Low Exposure	3	0	25.6 ±35.65	139.4	--	0.98

TABLE 3-321

TRACE METAL CONCENTRATIONS IN FISH PARTS: % ASH

(NINE MONTHS EXPOSURE TO INCINERATOR RESIDUE)

	Number Analyzed	Number below Sensitivity	Average % ± σ	Percent σ/X̄	Pooled Result	Critical Ratio
BONE						
Controls	10	0	8.08 ± 2.32	28.7	--	--
Low Exposure	4	0	8.29 ± 1.26	15.1	--	0.25
High Exposure	5	0	10.48 ± 0.42	4.0	--	3.17
GILLS						
Controls	9	0	5.25 ± 0.88	16.8	--	--
Low Exposure	4	0	5.26 ± 1.18	22.5	--	0.15
High Exposure	5	0	5.16 ± 2.19	42.4	--	0.09
GUT						
Controls	10	0	1.56 ± 0.32	20.4	--	--
Low Exposure	4	0	1.60 ± 0.27	17.1	--	0.26
High Exposure	5	0	1.55 ± 0.30	19.1	--	0.06
LIVER						
Controls	6	1	<1.38 ± 0.15	10.9	--	--
Low Exposure	4	4	<0.67 ± 0.46	69.2	--	0.30
High Exposure	1	1	<0.27 --	--	--	--
MUSCLE						
Controls	8	0	1.26 ± 0.50	39.6	--	--
Low Exposure	4	0	1.19 ± 0.14	11.4	--	0.37
High Exposure	5	0	1.39 ± 0.28	20.1	--	0.60
OVARY						
Controls	3	2	<0.70 ± 0.63	89.7	--	--
Low Exposure	1	1	<0.08 --	--	--	--
High Exposure	3	1	<2.24 ± 0.92	41.2	--	2.4
SKIN						
Controls	8	0	3.53 ± 0.87	24.7	--	--
Low Exposure	4	0	3.31 ± 0.36	10.8	--	0.62
High Exposure	5	0	3.18 ± 0.33	10.5	--	1.03
TESTES						
Controls	5	5	<1.81 ± 2.92	162.0	--	--
Low Exposure	3	1	<1.05 ± 0.80	76.7	--	0.55

c. Trace Metal Concentrations in Quahogs

Quahogs (Mercenaria mercenaria) exposed to 2 and 4 pounds of incinerator residue twice weekly (in pens). Samples were collected September, 1968. Those referred to as "1 year" had been exposed since June, 1967; "2 years", since May, 1966; "3 years", since August, 1965.

In this group there are a great many results which are statistically anomalous. Some trace metals appear to concentrate and others to be depleted.

In the one-year exposure group, chromium and copper appear to be depleted at both exposure levels, and zinc at the two-pound level.

After two years' exposure, zinc is again depleted at the two pound level and copper at both exposures.

After three years, copper is again depleted only at the four-pound level, and iron indicates depletion at the four-pound level.

TABLE 3-33a

TRACE METAL CONCENTRATIONS IN MARINE ORGANISMS: CADMIUM

		Number Analyzed	Number below Sensitivity	ppm ± σ	Percent σ/X̄	Pooled Result	Critical Ratio
QUAHOGS:	1 YEAR						
	Controls	10	0	0.237 ± 0.038	16.0	---	---
	2# Plot	10	0	0.246 ± 0.049	20.1	---	+0.5
	4# Plot	10	0	0.220 ± 0.030	13.7	---	-1.1
QUAHOGS:	2 YEARS						
	Controls	10	0	0.265 ± 0.053	20.0	---	---
	2# Plot	10	0	0.259 ± 0.042	16.4	---	-0.3
	4# Plot	10	0	0.237 ± 0.044	18.4	---	-1.3
QUAHOGS:	3 YEARS						
	Controls	7	0	0.261 ± 0.025	9.48	---	---
	2# Plot	10	0	0.277 ± 0.059	21.5	---	+0.8
	4# Plot	9	0	0.234 ± 0.053	22.5	---	-1.4

TABLE 3-33b

TRACE METAL CONCENTRATIONS IN MARINE ORGANISMS: CHROMIUM

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent $\sigma/\overline{X}$	Pooled Result	Critical Ratio
QUAHOGS: 1 YEAR						
Controls	10	0	0.69 ± 0.13	19.4	0.57	---
2# Plot	10	0	0.51 ± 0.079	15.5	0.54	-3.7
4# Plot	10	0	0.53 ± 0.16	29.9	0.45	-2.4
QUAHOGS: 2 YEARS						
Controls	10	6	<0.67 ± 0.32	47.5	0.65	---
2# Plot	10	7	<0.65 ± 0.31	47.6	0.55	-0.1
4# Plot	10	7	<0.51 ± 0.14	27.6	0.56	-1.5
QUAHOGS: 3 YEARS						
Controls	7	3	<0.57 ± 0.40	69.3	0.49	---
2# Plot	10	5	<0.51 ± 0.25	48.6	0.48	-0.4
4# Plot	9	6	<0.58 ± 0.24	42.0	0.48	+0.1

TABLE 3-33c

TRACE METAL CONCENTRATIONS IN MARINE ORGANISMS: COBALT

		Number Analyzed	Number below Sensitivity	ppm ± σ	Percent $\sigma/\overline{X}$	Pooled Result	Critical Ratio
QUAHOGS:	1 YEAR						
	Controls	10	0	1.70 ± 0.19	11.4	---	---
	2# Plot	10	0	1.76 ± 0.31	17.6	---	+0.5
	4# Plot	10	0	1.65 ± 0.16	9.42	---	-0.6
QUAHOGS:	2 YEARS						
	Controls	10	0	2.13 ± 0.30	14.3	---	---
	2# Plot	10	0	2.12 ± 0.20	9.61	---	-0.1
	4# Plot	10	0	2.05 ± 0.21	10.5	---	-0.7
QUAHOGS:	3 YEARS						
	Controls	7	0	2.50 ± 0.17	6.79	---	---
	2# Plot	10	0	2.63 ± 0.29	10.9	---	+1.2
	4# Plot	9	0	2.47 ± 0.41	16.7	---	-0.2

TABLE 3-33d

TRACE METAL CONCENTRATIONS IN MARINE ORGANISMS: COPPER

		Number Analyzed	Number below Sensitivity	ppm ± σ	Percent σ/$\overline{X}$	Pooled Result	Critical Ratio
QUAHOGS:	1 YEAR						
	Controls	10	0	3.14 ± 0.74	23.6	---	---
	2# Plot	10	0	2.10 ± 0.47	22.2	---	-3.8
	4# Plot	10	0	1.95 ± 0.37	19.1	---	-4.5
QUAHOGS:	2 YEARS						
	Controls	10	0	4.02 ± 1.05	26.2	---	---
	2# Plot	10	0	2.55 ± 0.51	20.1	---	-4.0
	4# Plot	10	0	2.11 ± 0.39	18.2	---	-5.4
QUAHOGS:	3 YEARS						
	Controls	7	0	3.96 ± 1.11	28.1	---	---
	2# Plot	*9	0	*3.31 ± 0.53	16.1	---	-1.4
	4# Plot	9	0	2.76 ± 1.04	37.7	---	-2.2

---

*Sample #4 excluded. 133 ppm

TABLE 3-33e

TRACE METAL CONCENTRATIONS IN MARINE ORGANISMS: IRON

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent $\sigma/\overline{X}$	Pooled Result	Critical Ratio
QUAHOGS: 1 YEAR						
Controls	10	0	3.29 ± 1.61	49.1	---	---
2# Plot	10	0	2.72 ± 2.07	76.2	---	-0.7
4# Plot	10	0	2.45 ± 0.86	35.2	---	-1.5
QUAHOGS: 2 YEARS						
Controls	10	0	4.67 ± 3.58	76.6	---	---
2# Plot	10	0	3.53 ± 1.76	49.7	---	-0.9
4# Plot	10	0	3.10 ± 2.25	72.8	---	-1.2
QUAHOGS: 3 YEARS						
Controls	7	0	7.49 ± 2.50	33.4	---	---
2# Plot	10	0	12.84 ± 7.41	57.7	---	+2.1
4# Plot	9	0	4.77 ± 1.25	26.3	---	-2.6

TABLE 3-33f

TRACE METAL CONCENTRATIONS IN MARINE ORGANISMS: LEAD

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent σ/X̄	Pooled Result	Critical Ratio
QUAHOGS: 1 YEAR						
Controls	10	0	0.985 ± 0.108	11.0	---	---
2# Plot	10	0	0.875 ± 0.199	22.7	---	-1.5
4# Plot	10	0	0.845 ± 0.150	17.8	---	-2.4
QUAHOGS: 2 YEARS						
Controls	10	0	1.05 ± 0.272	25.9	---	---
2# Plot	10	0	0.913 ± 0.189	20.8	---	-1.3
4# Plot	10	0	0.930 ± 0.193	20.8	---	-1.1
QUAHOGS: 3 YEARS						
Controls	7	0	0.910 ± 0.187	20.6	---	---
2# Plot	10	0	0.936 ± 0.189	20.2	---	+0.3
4# Plot	9	0	1.09 ± 0.359	32.8	---	+1.3

TABLE 3-33g

TRACE METAL CONCENTRATIONS IN MARINE ORGANISMS: MANGANESE

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent σ/X̄	Pooled Result	Critical Ratio
QUAHOGS: 1 YEAR						
Controls	10	0	1.37 ± 1.00	73.4	---	---
2# Plot	10	0	0.807 ± 0.600	74.3	---	-1.5
4# Plot	10	0	1.33 ± 0.940	70.8	---	-0.1
QUAHOGS: 2 YEARS						
Controls	10	0	0.771 ± 0.487	63.1	---	---
2# Plot	10	0	0.618 ± 0.348	56.3	---	-0.8
4# Plot	10	0	0.761 ± 0.707	92.9	---	-0.04
QUAHOGS: 3 YEARS						
Controls	7	0	1.01 ± 0.458	45.5	---	---
2# Plot	10	0	2.01 ± 1.76	87.4	---	+1.7
4# Plot	9	0	0.97 ± 0.57	59.0	---	-0.2

TABLE 3-33h

TRACE METAL CONCENTRATIONS IN MARINE ORGANISMS: NICKEL

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent σ/X̄	Pooled Result	Critical Ratio
QUAHOGS: 1 YEAR						
Controls	10	0	1.90 ± 0.286	15.1	1.23	---
2# Plot	10	0	2.15 ± 0.360	16.7	1.63	+1.7
4# Plot	10	0	1.84 ± 0.313	17.1	1.22	-0.4
QUAHOGS: 2 YEARS						
Controls	10	3	<2.19 ± 0.787	35.9	2.01	---
2# Plot	10	3	<2.14 ± 0.465	21.8	1.81	-0.2
4# Plot	10	1	<1.98 ± 0.461	23.3	2.01	-0.7
QUAHOGS: 3 YEARS						
Controls	7	2	<2.02 ± 0.618	30.6	1.65	---
2# Plot	10	1	<2.02 ± 0.667	33.0	1.82	-0
4# Plot	9	2	<2.04 ± 0.719	35.3	1.34	+0.1

TABLE 3-331

TRACE METAL CONCENTRATIONS IN MARINE ORGANISMS: ZINC

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent $\sigma/\overline{X}$	Pooled Result	Critical Ratio
QUAHOGS: 1 YEAR						
Controls	10	0	25.9 ± 7.41	28.6	---	---
2# Plot	10	0	18.8 ± 4.14	22.0	---	-2.6
4# Plot	10	0	21.9 ± 6.55	29.9	---	-1.3
QUAHOGS: 2 YEARS						
Controls	10	0	24.8 ± 3.91	15.8	---	---
2# Plot	10	0	19.2 ± 5.09	26.4	---	-2.8
4# Plot	10	0	20.2 ± 7.85	38.9	---	-1.7
QUAHOGS: 3 YEARS						
Controls	7	0	23.3 ± 4.07	17.5	---	---
2# Plot	10	0	25.8 ± 5.35	20.8	---	+1.1
4# Plot	9	0	22.9 ± 5.89	25.7	---	-0.2

TABLE 3-33J

TRACE METAL CONCENTRATIONS IN MARINE ORGANISMS: % ASH

	Number Analyzed	Number below Sensitivity	Average % ± σ	Percent σ/X̄	Pooled Result	Critical Ratio
QUAHOGS: 1 YEAR						
Controls	10	---	2.46 ± 0.125	5.08	---	---
2# Plot	10	---	2.51 ± 0.241	9.62	---	+0.6
4# Plot	10	---	2.38 ± 0.075	3.17	---	-1.7
QUAHOGS: 2 YEARS						
Controls	10	---	2.64 ± 0.458	17.4	---	---
2# Plot	10	---	2.46 ± 0.113	4.61	---	-1.2
4# Plot	10	---	2.41 ± 0.135	5.60	---	-1.5
QUAHOGS: 3 YEARS						
Controls	7	---	2.51 ± 0.173	6.89	---	---
2# Plot	10	---	2.47 ± 0.194	7.85	---	-0.4
4# Plot	5	---	2.30 ± 0.177	7.71	---	-2.0

d. Trace Metal Concentrations in Quahogs and Scallops

Quahogs (Mercenaria mercenaria): Exposed to 2 and 4 pounds of incinerator residue twice weekly (in pens) from August through October, 1966.

No trace metal is statistically increased in this exposure group. A reduction in the amount of trace iron is significant at the 0.05 level.

Scallops (Placopecten magellanicus): Exposed to 2 pounds of incinerator residue twice weekly for 42 days during May and June, 1968.

Sample 488 was considered contaminated with nickel, as the concentration was about 50 times that of other samples, and it was rejected in calculation of the nickel average.

Copper, lead, and manganese are statistically increased in exposed (treated) animals.

TABLE 3-34a

TRACE METAL CONCENTRATIONS IN MARINE ORGANISMS: CADMIUM

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent σ/X̄	Pooled Result	Critical Ratio
QUAHOGS						
Controls	9	0	0.185 ± .058	31.3	--	--
2# Plot	8	0	0.194 ± .050	25.7	--	0.3
4# Plot	10	0	0.170 ± .058	34.3	--	0.6
SCALLOPS						
Controls	11	0	1.65 ± .271	16.4	--	--
Treated	11	0	1.86 ± .550	29.4	--	1.1

TABLE 3-34b

TRACE. METAL CONCENTRATIONS IN MARINE ORGANISMS: CHRONIUM

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent σ/X̄	Pooled Result	Critical Ratio
QUAHOGS						
Controls	10	10	<1.30 ± 0.901	69.1	0.254	--
2# Plot	8	8	<0.832 ± 0.494	59.3	0.232	1.40
4# Plot	11	11	<1.56 ± 1.07	69.0	0.250	0.603
SCALLOPS						
Controls	10	9	<0.139 ± 0.0376	27.0	0.125	--
Treated	10	3	<0.141 ± 0.0433	30.6	--	0.110

TABLE 3-34c

TRACE METAL CONCENTRATIONS IN MARINE ORGANISMS: COBALT

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent σ/X̄	Pooled Result	Critical Ratio
QUAHOGS						
Controls	9	2	<1.19 ± 0.362	30.5	1.14	--
2# Plot	8	0	1.19 ± 0.182	15.3	--	>0
4# Plot	10	2	<1.27 ± 0.497	39.0	1.18	>0.4
SCALLOPS						
Controls	11	0	0.601± 0.117	19.6	--	--
Treated	11	0	0.672± 0.199	29.6	--	1.0

TABLE 3-34d

TRACE METAL CONCENTRATIONS IN MARINE ORGANISMS: COPPER

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent σ/X̄	Pooled Result	Critical Ratio
QUAHOGS						
Controls	8	0	3.56 ± 1.08	30.3	--	--
2# Plot	8	0	3.51 ± 1.28	36.5	--	0.1
4# Plot	9	0	3.59 ± 1.07	30.0	--	0.1
SCALLOPS						
Controls	11	0	1.08 ± 0.535	49.4	--	--
Treated	11	0	1.78 ± 0.964	54.2	--	2.1

TABLE 3-34e

TRACE. METAL CONCENTRATIONS IN MARINE ORGANISMS: IRON

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent σ/$\bar{X}$	Pooled Result	Critical Ratio
QUAHOGS						
Controls	9	0	16.0 ± 8.50	53.3	--	--
2# Plot	8	0	10.4 ± 5.04	48.3	--	1.7
4# Plot	10	0	9.50 ± 5.39	56.7	--	2.0
SCALLOPS						
Controls	11	0	4.29 ± 0.982	22.9	--	--
Treated	10	0	4.73 ± 2.92	61.7	--	0.5

TABLE 3-34f

TRACE METAL CONCENTRATIONS IN MARINE ORGANISMS: LEAD

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent σ/X̄	Pooled Result	Critical Ratio
QUAHOGS						
Controls	9	1	<1.30 ± 0.543	41.8	.737	--
2# Plot	8	0	1.29 ± 0.952	73.8	--	>0.03
4# Plot	9	0	1.16 ± 0.541	46.9	--	>0.5
SCALLOPS						
Controls	11	0	0.407 ± 0.117	28.6	--	--
Treated	10	0	0.640 ± 0.287	44.8	--	2.4

TABLE 3-34g

TRACE METAL CONCENTRATIONS IN MARINE ORGANISMS: MANGANESE

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent σ/$\overline{X}$	Pooled Result	Critical Ratio
QUAHOGS						
Controls	8	0	1.89 ± 1.35	71.7	--	--
2# Plot	8	0	2.24 ± 1.87	83.3	--	0.4
4# Plot	10	1	<1.07 ± 0.535	49.8	0.690	>1.6
SCALLOPS						
Controls	10	0	0.140 ± 0.071	50.9	--	--
Treated	10	0	0.351 ± 0.256	72.9	--	2.5

TABLE 3-34h

TRACE. METAL CONCENTRATIONS IN MARINE ORGANISMS: NICKEL

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent $\sigma/\bar{X}$	Pooled Result	Critical Ratio
QUAHOGS						
Controls	9	7	<1.70 ± 1.16	68.2	0.585	--
2# Plot	8	3	<1.68 ± 0.958	56.9	0.995	0.039
4# Plot	10	10	<2.17 ± 1.295	59.6	0.705	0.835
SCALLOPS						
Controls	8	8	<0.253 ± 0.054	21.3	0.122	--
Treated	9	9	<0.326 ± 0.119	36.7	0.393*	1.66

---

*less sample #488.

TABLE 3-341

TRACE METAL CONCENTRATIONS IN MARINE ORGANISMS: ZINC

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent $\sigma/\overline{X}$	Pooled Result	Critical Ratio
QUAHOGS						
Controls	9	0	13.3 ± 2.51	18.9	--	--
2# Plot	8	0	18.1 ± 7.70	42.6	--	1.7
4# Plot	9	0	10.9 ± 5.06	46.4	--	1.3
SCALLOPS						
Controls	11	0	7.15 ± 5.75	80.4	--	--
Treated	11	0	8.40 ± 4.55	54.0	--	0.6

TABLE 3-34j

TRACE METAL CONCENTRATIONS IN MARINE ORGANISMS: % ASH

	Number Analyzed	Number below Sensitivity	Average % ± σ	Percent $\sigma/\overline{X}$	Pooled Result	Critical Ratio
QUAHOGS						
Controls	9	0	2.47±0.52	21.2	-	-
2# Plot	8	0	2.71±0.47	17.5	-	1.00
4# Plot	11	0	2.49±0.63	25.4	-	0.08
SCALLOPS						
Controls	11	0	2.72±0.73	26.8	-	-
Treated	11	0	2.77±0.59	21.1	-	0.18

e. Trace Metal Concentrations in Scallop Parts

Scallops were held in tanks exposed to various concentrations of sea water extracts of incinerator residue for 9 days during December, 1967.

Statistically the gill appears to concentrate cadmium, cobalt, iron, lead, and manganese; the muscle concentrates cadmium, cobalt, and manganese; the mantle concentrates cobalt and lead. In the liver, cobalt appears to be concentrated; however, a great many of these results are less than the analytical sensitivity and are therefore unreliable. Copper and iron appear to be diminished in the liver.

TABLE 3-35a

TRACE METAL CONCENTRATIONS IN SCALLOP PARTS: COPPER

(NINE DAY EXPOSURE TO EXTRACTS OF INCINERATOR RESIDUE)

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent σ/x̄	Pooled Result	Critical Ratio
GILLS						
Controls	5	0	1.49 ± 0.432	29.1	--	--
1.0% Extract	5	0	1.60 ± 0.168	10.5	--	0.53
1.8% "	5	0	1.79 ± 0.348	20.0	--	0.77
3.2% "	5	0	1.92 ± 0.343	17.9	--	1.74
5.6% "	5	0	1.38 ± 0.144	10.5	--	0.29
10.0% "	4	0	1.54 ± 0.741	47.9	--	0.09
MUSCLE						
Controls	3	0	0.271 ± 0.067	24.9	--	--
1.0% Extract	5	0	0.348 ± 0.208	59.9	--	0.69
1.8% "	4	0	0.540 ± 0.110	20.4	--	4.02
3.2% "	5	0	0.258 ± 0.076	29.3	--	0.25
5.6% "	5	0	0.384 ± 0.124	32.3	--	1.69
10.0% "	4	0	0.487 ± 0.120	24.7	--	3.19
MANTLE						
Controls	4	0	0.579 ± 0.066	11.4	--	--
1.0% Extract	5	0	0.388 ± 0.068	17.5	--	0.32
1.8% "	5	0	0.656 ± 0.331	50.5	--	0.13
3.2% "	5	0	0.500 ± 0.179	35.9	--	0.60
5.6% "	5	0	0.507 ± 0.156	30.7	--	0.12
10.0% "	4	0	0.452 ± 0.074	16.3	--	0.21
GONADS						
Controls	1	0	1.01 ± --	--	--	--
1.0% Extract	5	0	2.64 ± 1.75	66.4	--	--
1.8% "	5	0	1.71 ± 0.881	51.5	--	--
3.2% "	5	0	1.53 ± 0.380	24.9	--	--
5.6% "	4	0	0.704 ± 0.043	6.1	--	--
10.0% "	4	0	2.03 ± 1.33	65.3	--	--
LIVER						
Controls	4	0	19.1 ± 7.91	41.3	--	--
1.0% Extract	5	0	16.6 ± 5.56	33.5	--	0.53
1.8% "	5	0	8.39 ± 10.3	122.6	--	2.35
3.2% "	5	0	11.4 ± 5.09	44.5	--	1.9
5.6% "	5	0	10.5 ± 2.30	21.9	--	2.1
10.0% "	4	0	13.5 ± 2.67	19.8	--	1.4

TABLE 3-35b

TRACE METAL CONCENTRATIONS IN SCALLOP PARTS: **CADMIUM**

(NINE DAY EXPOSURE TO EXTRACTS OF INCINERATOR RESIDUE)

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent σ/$\bar{x}$	Pooled Result	Critical Ratio
GILLS						
Controls	5	0	0.40 ± 0.181	45.2	--	--
1.0% Extract	5	0	1.52 ± 0.182	12.0	--	9.8
1.8% "	5	0	1.87 ± 0.748	39.9	--	4.3
3.2% "	5	0	2.12 ± 1.380	65.1	--	2.8
5.6% "	5	0	2.16 ± 0.460	21.3	--	8.0
10.0%	4	0	2.03 ± 0.449	22.1	--	6.8
MUSCLE						
Controls	3	0	0.188 ± 0.0142	7.54	--	--
1.0% Extract	5	0	0.296 ± 0.183	61.9	--	1.3
1.8% "	4	0	0.330 ± 0.135	40.9	--	2.1
3.2% "	5	0	0.206 ± 0.044	21.4	--	2.2
5.6% "	5	0	0.261 ± 0.0824	31.5	--	1.9
10.0% "	4	0	0.248 ± 0.0987	39.8	--	1.2
MANTLE						
Controls	4	0	0.536 ± 0.129	24.1	--	--
1.0% Extract	5	0	0.446 ± 0.0467	10.5	--	1.3
1.8% "	5	0	0.506 ± 0.0295	5.83	--	0.45
3.2% "	5	0	0.374 ± 0.137	36.6	--	1.8
5.6% "	5	0	0.574 ± 0.0954	16.6	--	0.49
10.0% "	4	0	0.600 ± 0.0646	10.8	--	0.89
GONADS						
Controls	1	0	1.459 ± --	--	--	--
1.0% Extract	5	0	0.811 ± 0.592	72.8	--	--
1.8% "	5	0	0.414 ± 0.246	59.4	--	--
3.2% "	5	0	0.908 ± 0.897	98.7	--	--
5.6% "	5	0	0.514 ± 0.368	71.6	--	--
10.0% "	4	0	0.570 ± 0.358	62.8	--	--
LIVER						
Controls	4	0	22.4 ± 3.41	15.2	--	--
1.0% Extract	5	0	22.1 ± 3.95	17.9	--	0.12
1.8% "	5	0	28.4 ±14.7	51.7	--	0.88
3.2% "	5	0	20.6 ± 5.22	25.4	--	0.62
5.6% "	5	0	26.6 ± 7.51	28.2	--	1.11
10.0% "	4	0	26.8 ± 4.98	18.6	--	1.45

TABLE 3-35c

TRACE METAL CONCENTRATIONS IN SCALLOP PARTS: COBALT

(NINE DAY EXPOSURE TO EXTRACTS OF INCINERATOR RESIDUE)

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent σ/X̄	Pooled Result	Critical Ratio
GILLS						
Controls	5	1	< 0.785 ± 0.208	26.5	--	--
1.0% Extract	5	0	2.00 ± 0.530	26.5	--	4.8
1.8% "	5	1	< 1.42 ± 0.265	18.7	--	4.2
3.2% "	5	0	3.21 ± 1.96	60.8	--	2.8
5.6% "	5	0	2.05 ± 0.174	8.51	--	10.4
10.0% "	3	1	< 1.55 ± 0.162	10.4	--	5.8
MUSCLE						
Controls	3	0	0.356 ± 0.0177	4.97	--	--
1.0% Extract	5	0	0.572 ± 0.0505	8.22	--	8.8
1.8% "	4	1	< 0.556 ± 0.0794	14.3	--	4.9
3.2% "	5	0	0.554 ± 0.0779	14.1	--	5.5
5.6% "	5	0	0.736 ± 0.0784	10.7	--	10.4
10.0% "	4	0	0.627 ± 0.227	36.3	--	2.4
MANTLE						
Controls	4	0	1.01 ± 0.224	22.1	--	--
1.0% Extract	5	0	1.36 ± 0.0834	6.13	--	3.0
1.8% "	5	0	1.34 ± 0.160	11.9	--	2.5
3.2% "	5	1	< 1.44 ± 0.438	30.3	--	1.9
5.6% "	5	0	1.64 ± 0.096	5.86	--	5.2
10.0% "	4	0	1.84 ± 0.166	9.0	--	5.9
GONADS						
Controls	1	0	0.936 ± --	--	--	--
1.0% Extract	5	2	< 1.62 ± 0.869	53.7	--	--
1.8% "	5	5	< 1.36 ± 0.498	36.6	--	--
3.2% "	5	0	2.74 ± 1.34	49.1	--	--
5.6% "	5	0	1.01 ± 0.166	16.5	--	--
10.0% "	4	4	< 1.80 ± 1.07	59.5	--	--
LIVER						
Controls	4	1	< 0.797 ± 0.087	10.9	--	--
1.0% Extract	5	4	< 1.53 ± 0.241	15.7	--	6.3
1.8% "	5	5	< 1.98 ± 0.444	22.4	--	5.8
3.2% "	5	2	< 1.50 ± 0.358	23.2	--	4.4
5.6% "	5	2	< 1.62 ± 0.495	30.6	< 0.30	3.6
10.0% "	4	4	< 1.90 ± 0.141	7.4	--	13.3

TABLE 3-35d

TRACE METAL CONCENTRATIONS IN SCALLOP PARTS: COPPER

(NINE DAY EXPOSURE TO EXTRACTS OF INCINERATOR RESIDUE)

	Number Analyzed	Number below Sensitivity	ppm	±	σ	Percent σ/X̄	Pooled Result	Critical Ratio
GILLS								
Controls	5	0	1.49	±	0.432	29.1	--	--
1.0% Extract	5	0	1.60	±	0.168	10.5	--	0.53
1.8% "	5	0	1.79	±	0.348	20.0	--	0.77
3.2% "	5	0	1.92	±	0.343	17.9	--	1.74
5.6% "	5	0	1.38	±	0.144	10.5	--	0.29
10.0% "	4	0	1.54	±	0.741	47.9	--	0.09
MUSCLE								
Controls	3	0	0.271	±	0.0674	24.9	--	--
1.0% Extract	5	0	0.348	±	0.208	59.9	--	0.13
1.8% "	4	0	0.540	±	0.110	20.4	--	0.60
3.2% "	5	0	0.258	±	0.0756	29.3	--	0.25
5.6% "	5	0	0.384	±	0.124	32.3	--	0.19
10.0% "	4	0	0.437	±	0.120	24.7	--	0.37
MANTLE								
Controls	4	0	0.579	±	0.066	11.4	--	--
1.0% Extract	5	0	0.388	±	0.0678	17.5	--	0.32
1.8% "	5	0	0.656	±	0.331	50.5	--	0.13
3.2% "	5	0	0.500	±	0.179	35.8	--	0.60
5.6% "	5	0	0.507	±	0.156	30.7	--	0.12
10.0% "	4	0	0.452	±	0.0738	16.3	--	0.21
GONADS								
Controls	1	0	1.01	±	--	--	--	--
1.0% Extract	5	0	2.64	±	1.75	66.4	--	--
1.8% "	5	0	1.71	±	0.881	51.5	--	--
3.2% "	5	0	1.53	±	0.380	24.9	--	--
5.6% "	4	0	0.704	±	0.043	6.1	--	--
10.0% "	4	0	2.03	±	1.33	65.3	--	--
LIVER								
Controls	4	0	19.1	±	7.91	41.3	--	--
1.0% Extract	5	0	16.6	±	5.56	33.5	--	0.53
1.8% "	5	0	8.39	±	10.3	122.8	--	2.35
3.2% "	5	0	11.4	±	5.07	44.5	--	1.9
5.6% "	5	0	10.5	±	2.30	21.9	--	2.1
10.0% "	4	0	13.5	±	2.67	19.8	--	1.4

TABLE 3-35e

TRACE METAL CONCENTRATIONS IN SCALLOP PARTS: IRON

(NINE DAY EXPOSURE TO EXTRACTS OF INCINERATOR RESIDUE)

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent σ/X̄	Pooled Result	Critical Ratio
GILLS						
Controls	5	0	6.37 ± 5.15	80.9	--	--
1.0% Extract	5	0	15.1 ± 4.21	27.8	--	2.9
1.8% "	5	0	18.3 ± 5.92	32.0	--	3.5
3.2% "	5	0	10.6 ± 5.92	55.8	--	1.2
5.6% "	5	0	22.7 ± 9.08	40.0	--	4.9
10.0% "	4	0	16.2 ± 5.45	33.6	--	2.8
MUSCLE						
Controls	4	0	0.826 ± 0.20	24.1	--	--
1.0% Extract	5	0	0.669 ± 0.158	23.7	--	1.28
1.8% "	4	0	1.17 ± 0.329	28.1	--	1.79
3.2% "	5	0	0.580 ± 0.150	26.0	--	2.04
5.6% "	5	0	0.779 ± 0.226	29.0	--	0.33
10.0% "	4	0	0.785 ± 0.277	35.3	--	0.24
MANTLE						
Controls	5	0	4.54 ± 2.13	47.0	--	--
1.0% Extract	5	0	2.61 ± 0.249	9.53	--	2.01
1.8% "	5	0	4.28 ± 1.04	24.4	--	0.24
3.2% "	5	0	3.05 ± 1.31	43.0	--	1.33
5.6% "	5	0	4.38 ± 0.581	13.3	--	0.16
10.0% "	4	0	4.19 ± 1.25	29.8	--	0.31
GONADS						
Controls	1	0	16.7 ± --	--	--	--
1.0% Extract	5	0	7.66 ± 4.00	52.2	--	--
1.8% "	5	0	3.89 ± 1.25	32.1	--	--
3.2% "	5	0	4.87 ± 4.97	102.0	--	--
5.6% "	5	0	2.68 ± 0.801	29.9	--	--
10.0% "	4	0	4.72 ± 2.87	60.8	--	--
LIVER						
Controls	4	0	51.1 ± 8.21	16.1	--	--
1.0% Extract	5	0	38.7 ± 6.22	16.0	--	2.50
1.8% "	5	0	45.4 ± 19.1	42.1	--	0.60
3.2% "	5	0	35.6 ± 9.45	26.6	--	2.63
5.6% "	5	0	35.5 ± 8.81	24.8	--	2.74
10.0% "	4	0	45.6 ± 7.50	16.4	--	0.99

TABLE 3-35f

. TRACE METAL CONCENTRATIONS IN SCALLOP PARTS: LEAD

(NINE DAY EXPOSURE TO EXTRACTS OF INCINERATOR RESIDUE)

	Number Analyzed	Number below Sensitivity	ppm ± σ		Percent σ/X̄	Pooled Result	Critical Ratio
GILLS							
Controls	5	2	<1.07 ±	0.285	26.5	--	--
1.0% Extract	5	0	2.08 ±	0.862	39.8	--	2.6
1.8% "	5	1	<1.30 ±	0.150	11.6	--	1.6
3.2% "	5	2	<1.82 ±	0.763	42.0	--	2.1
5.6% "	5	2	<1.51 ±	0.174	11.6	--	2.9
10.0% "	4	2	<1.96 ±	0.671	34.3	--	2.5
MUSCLE							
Controls	3	0	0.377±	0.0462	12.3	--	--
1.0% Extract	5	0	0.708±	0.265	37.5	--	2.7
1.8% "	4	0	0.475±	0.132	27.8	--	1.4
3.2% "	5	2	<0.406±	0.274	67.4	--	0.23
5.6% "	5	1	<0.367±	0.0794	21.6	--	0.23
10.0% "	4	0	0.605±	0.0283	4.7	--	7.6
MANTLE							
Controls	4	0	0.475±	0.132	27.9	--	--
1.0% Extract	5	0	0.966±	0.140	14.5	--	5.4
1.8% "	5	2	<0.838±	0.237	28.3	--	2.9
3.2% "	5	2	<1.94 ±	2.49	129.0	--	1.3
5.6% "	5	1	<0.873±	0.217	24.9	--	3.4
10.0% "	4	2	<0.837±	0.292	34.9	--	2.3
GONADS							
Controls	1	0	0.90 ±	--	--	--	--
1.0% Extract	5	1	<1.04 ±	0.612	59.0	--	--
1.8% "	5	4	<0.87 ±	0.314	35.9	--	--
3.2% "	5	3	<1.13 ±	0.317	28.0	--	--
5.6% "	5	5	<1.13 ±	0.249	22.0	--	--
10.0% "	4	4	<1.51 ±	0.792	52.4	--	--
LIVER							
Controls	4	0	2.08 ±	0.479	23.0	--	--
1.0% Extract	5	0	3.07 ±	0.840	27.3	--	2.21
1.8% "	5	0	2.24 ±	0.693	31.0	--	0.41
3.2% "	5	1	<1.89 ±	0.301	15.9	--	0.68
5.6% "	5	2	<1.82 ±	0.236	13.0	--	0.98
10.0% "	4	0	2.31 ±	0.485	21.0	--	0.69

TABLE 3-35g

TRACE METAL CONCENTRATIONS IN SCALLOP PARTS: MANGANESE
(NINE DAY EXPOSURE TO EXTRACTS OF INCINERATOR RESIDUE)

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent σ/X̄	Pooled Result	Critical Ratio
GILLS						
Controls	5	3	<0.372 ± 0.141	37.9	0.335	--
1.0% Extract	5	1	<1.31 ± 0.457	34.9	--	4.38
1.8% "	5	1	<0.507 ± 0.161	31.8	--	1.41
3.2% "	5	4	<1.34 ± 0.916	68.1	--	2.34
5.6% "	5	5	<0.852 ± 0.0918	10.8	0.840	3.33
10.0% "	4	3	<1.20 ± 0.673	56.2	--	2.42
MUSCLE						
Controls	3	0	0.086 ± 0.00513	5.94	0.199	--
1.0% Extract	5	3	<0.205 ± 0.0502	24.5	--	11.2
1.8% "	4	3	<0.133 ± 0.0419	31.4	--	2.22
3.2% "	5	5	<0.180 ± 0.0224	12.4	--	9.02
5.6% "	5	3	<0.237 ± 0.0556	23.4	0.156	6.03
10.0% "	4	2	<0.406 ± 0.207	51.0	--	3.09
MANTLE						
Controls	4	2	<0.290 ± 0.137	47.1	--	--
1.0% Extract	5	5	<0.372 ± 0.0585	15.7	--	1.12
1.8% "	5	5	<0.256 ± 0.105	40.9	--	0.29
3.2% "	5	4	<0.431 ± 0.185	42.8	--	1.32
5.6% "	5	5	<0.450 ± 0.146	32.5	--	1.69
10.0% "	4	4	<0.460 ± 0.191	41.6	--	1.44
GONADS						
Controls	1	0	0.332 ± --	--	--	--
1.0% Extract	5	1	<0.892 ± 0.414	46.4	--	--
1.8% "	5	5	<0.396 ± 0.149	37.5	--	--
3.2% "	5	2	<0.791 ± 0.317	40.1	--	--
5.6% "	5	5	<0.724 ± 0.147	20.3	--	--
10.0% "	4	4	<1.73 ± 1.26	72.8	--	--
LIVER						
Controls	4	0	0.565 ± 0.189	33.4	--	--
1.0% Extract	5	3	<0.960 ± 0.198	20.6	--	3.05
1.8% "	5	5	<0.620 ± 0.0707	11.4	--	0.55
3.2% "	5	5	<1.01 ± 0.280	27.9	--	2.83
5.6% "	5	4	<1.11 ± 0.304	27.3	1.433	3.29
10.0% "	4	3	<1.13 ± 0.257	22.8	--	3.54

TABLE 3-35h

TRACE METAL CONCENTRATIONS IN SCALLOP PARTS: ZINC
(NINE DAY EXPOSURE TO EXTRACTS OF INCINERATOR RESIDUE)

	Number Analyzed	Number below Sensitivity	ppm ± σ	Percent σ/X̄	Pooled Result	Critical Ratio
GILLS						
Controls	5	0	24.3 ± 18.6	76.9	--	--
1.0% Extract	5	0	26.5 ± 4.69	17.7	--	0.26
1 8% "	5	0	16.7 ± 5.7	34.0	--	0.87
3.2% "	5	0	30.9 ± 12.7	41.1	--	0.65
5.6% "	5	0	16.7 ± 2.33	13.9	--	0.90
10.0% "	4	0	18.5 ± 1.49	8.05	--	0.69
MUSCLE						
Controls	3	0	8.84 ± 1.72	19.4	--	--
1.0% Extract	5	0	10.9 ± 2.46	22.7	--	0.62
1.8% "	4	0	9.51 ± 1.92	20.2	--	0.20
3.2% "	5	0	8.31 ± 0.594	7.15	--	0.17
5.6% "	5	0	8.31 ± 0.417	5.02	--	0.17
10.0% "	4	0	10.45 ± 2.53	24.2	--	0.48
MANTLE						
Controls	4	0	13.9 ± 2.07	14.9	--	--
1.0% Extract	5	0	16.7 ± 2.91	17.4	--	1.7
1.8% "	5	0	15.3 ± 0.982	6.5	--	1.2
3.2% "	5	0	15.1 ± 6.7	44.6	--	0.38
5.6% "	5	0	11.7 ± 2.01	17.2	--	1.6
10.0% "	4	0	10.5 ± 1.29	12.3	--	2.8
GONADS						
Controls	1	0	23.9 ± --	--	--	--
1.0% Extract	5	0	43.6 ± 29.7	68.2	--	--
1.8% "	5	0	38.1 ± 35.6	92.5	--	--
3.2% "	5	0	22.2 ± 11.1	50.1	--	--
5.6% "	5	0	12.5 ± 12.0	95.5	--	--
10.0% "	4	0	40.4 ± 33.9	84.0	--	--
LIVER						
Controls	4	0	20.2 ± 3.52	17.5	--	--
1.0% Extract	5	0	24.5 ± 4.67	19.1	--	1.6
1.8% "	5	0	31.2 ± 13.8	44.3	--	1.7
3.2% "	5	0	22.0 ± 4.45	20.2	--	0.68
5.6% "	5	0	20.6 ± 4.92	23.9	--	0.14
10.0% "	4	0	25.4 ± 3.57	14.1	--	2.1

TABLE 3-351

TRACE METAL CONCENTRATIONS IN SCALLOP PARTS: % ASH
(NINE DAY EXPOSURE TO EXTRACTS OF INCINERATOR RESIDUE)

	Number Analyzed	Number below Sensitivity	Average % ± σ	Percent σ/X̄	Pooled Result	Critical Ratio
GILLS						
Controls	5	0	2.15 ± 0.19	9.0	-	-
1.0% Extract	3	0	2.37 ± 0.22	9.3	-	1.48
1.8% "	5	0	2.49 ± 0.36	14.5	-	1.86
3.2% "	5	0	2.37 ± 0.62	26.2	-	0.76
5.6% "	5	0	2.30 ± 0.15	6.6	-	1.38
10.0% "	4	0	2.30 ± 0.17	7.2	-	1.25
MUSCLE						
Controls	4	0	1.38 ± 0.02	1.7	-	-
1.0% Extract	5	0	1.75 ± 0.13	7.7	-	6.25
1.8% "	5	0	1.56 ± 0.37	23.5	-	1.03
3.2% "	5	0	1.54 ± 0.12	7.8	-	2.92
5.6% "	5	0	1.55 ± 0.16	10.2	-	2.36
10.0% "	4	0	1.37 ± 0.06	4.5	-	0.32
MANTLE						
Controls	5	0	2.52 ± 0.50	19.9	-	-
1.0% Extract	5	0	2.26 ± 0.09	4.0	-	1.14
1.8% "	5	0	2.18 ± 0.12	5.6	-	1.48
3.2% "	5	0	2.18 ± 0.08	3.5	-	1.50
5.6% "	5	0	2.13 ± 0.05	2.5	-	1.73
10.0% "	4	0	2.34 ± 0.31	13.4	-	0.66
GONADS						
Controls	4*	0		-	2.56	-
1.0% Extract	5	0	2.13 ± 0.19	9.1	-	-
1.8% "	5	0	2.03 ± 0.18	8.9	-	-
3.2% "	5	0	1.99 ± 0.22	11.3	-	-
5.6% "	5	0	2.02 ± 0.36	17.8	-	-
10.0% "	4	0	2.06 ± 0.85	41.1	-	-
LIVER						
Controls	4	0	2.06 ± 0.15	7.5	-	-
1.0% Extract	5	0	1.80 ± 0.15	8.5	-	2.59
1.8% "	5	0	2.45 ± 0.53	21.8	-	1.57
3.2% "	5	0	1.88 ± 0.14	7.5	-	1.85
5.6% "	5	0	1.98 ± 0.27	13.5	-	0.56
10.0% "	4	0	2.12 ± 0.15	7.0	-	0.57

*Average of 4 organs pooled.

E. Discussion of Results

To determine the effect of sea disposal of incinerator residue on marine organisms, a number of species were exposed to residue from the Boston Municipal Incinerator for varying periods of time (See also Sect. 4). This portion of the report is concerned principally with the trace metal content of the incinerator residue and its effect on the marine environment and the organisms that inhabit it.

The chemical composition of the Boston incinerator residue is somewhat variable. In the samples analyzed, the major portion (about 63%) consisted of silicates and refractory oxides insoluble in acids. About 10% of the total consisted of aluminum, calcium, sodium, and potassium, and 14% of anions such as carbonates, phosphates, chlorides, and sulfates. An average of 8% was lost on ignition and assumed to be organic. Iron made up about 4% of the total, and trace metals about 1%. The trace metals probably occur primarily either as the metal or in the form of oxides as a result of incineration. As such, they would be insoluble or nearly so, particularly in sea water (see tables 3-22 and 3-23). As residue is added to sea water there is a rise in pH due principally to dissolution of the alkali metals. Most of the trace metals, if at all soluble, would reprecipitate under these conditions or form colloidal hydroxide suspensions. Iron in the amounts found (if soluble) would act as a nucleus for the coprecipitation of the other metals.

Redfield and Walford (17) have studied the sea disposal of 3800 tons per day of a mixture containing about 10% ferrous sulfate and 8.5% sulfuric acid. They anticipated effects of iron, sulfate, pH, and oxidation. At a disposal rate of 18 tons per minute and a vessel speed of 6 knots, iron hydroxide was visible as a suspension for 3 to 4 hours. In this form the iron was mixed and dispersed by ocean currents to the extent that after one year of operation no accumulation of iron in either water or sediment was measurable. Although the report states that the pH returns to 7 within 25 minutes, the normal pH of sea water is over 8, and no estimate is given for time required for return to this level.

It may be concluded that due to the relative insolubility of the trace metals in sea water, any adverse effects of residue on marine life would be due primarily to extreme species sensitivity to a particular metal, to solubility of ingested particulates in body fluids, or to mechanical effects of particulates such as clogging of gills. Toxicity of the sea water-soluble metals (primarily sodium and potassium) is probably low, and temporary high concentrations due to residue dumping would be rapidly diluted to enable recovery from any adverse effects. Pringle (5) has shown that there is a direct relationship between the rate of uptake and depletion for a given metal, so that if batch dumping is adhered to, organisms other than bottom feeders would have an opportunity to recover from one exposure before another occurred.

The increases in trace metals in the edible portions of the organisms studied would not be hazardous to human welfare.

APPENDIX 3-1

PROCEDURE FOR MARINE LIFE ANALYSES

Number and weigh a series of freeze-dry flasks. Cut up each frozen sample and place in a flask, moving quickly to keep thawing to a minimum. Reweigh full flask to get sample weight. Seal the flasks with Parafilm and replace immediately in the freezer to refreeze whatever material was melted during handling.

When sample is completely frozen in the flask, (2 or 3 hours) attach to freeze dryer and allow sample to dry for at least 6 hours, until the flask no longer feels cold to the touch. Remove flasks from dryer and weigh to determine dry weight of sample. Transfer to pre-weighed beaker, using the smallest size beaker that will contain the sample, and weigh again (weigh small samples on weighing paper). Identification of these beakers should be done by writing on frosted portion with ordinary lead pencil.

Place beakers in the muffle furnace at 550°C for at least 4 hours, until only white and grey ash remain. Remove and allow to cool, covering beakers with watch glasses. Weigh sample in beaker or on weighing paper on Mettler balance. Return sample to beaker.

Dissolve ash in mixture of equal parts of HCl and HNO_3 (conc. shelf reagents.) and distilled water. Use about 15 ml of mixture for a sample with orig. weight up to about 20 g. If original sample weight was more than this, increase accordingly. Heat this on the hot plate, in a hood, at low temp. to evaporate to dryness. Add about 5 ml H_2O and 0.5 ml 6N HCl. Heat and swirl to redissolve ash. Filter and rinse beaker, adding rinses to sample to make up to 20 ml. This can be filtered directly into a 25 ml graduated cylinder, adding rinse water as needed to make up to 20 ml. The sample will be stored in a plastic vial, and mixing can be achieved by pouring back and forth from cylinder to vial 2 or 3 times. One objective here is to get the sample into as little solution as possible, making at least 20 ml. If salts are precipitating out of solution, it may be necessary to make up to 30 or 40 ml. If sample must be made up to a greater volume, add a proportionately larger amount of HCl to make final normality 0.10 to 0.15.

LARGE SAMPLES If a sample is too big to be put into one freeze-dry flask (e.g. some whole fish), cut up and put into several flasks, adding weights. If possible, combine these parts again after freeze drying and muffle the whole sample in one large beaker. If this is not possible, combine ash after muffling.

POOL SAMPLES If analysis has shown a group of samples to be below analytical sensitivity in concentrations of some elements, it may be necessary to pool a number of samples to analyze. Do this after all other routine analysis have been performed, so that only "left-over" solution is used.

Measure the amount of solution that can be obtained from each sample, using whole ml amounts (no fractions of ml), Draw solution into measuring pipet and run maximum ml available into a small beaker. Calculate the amount of material obtained from each sample:

$$\frac{\text{Amount pooled (ml)}}{\text{original vol. (ml)}} \text{ X orig. sample wt.} = \text{weight in pool}$$

Add the weights of these samples to get the total weight in the pooled sample.

Evaporate this on a hot plate until salts start to crystallize out, and transfer to a graduated cylinder. Rinse beaker and add to cylinder. Make up to minimum volume at which total solution takes place.

Incinerator Residue: Samples are prepared by taking about 100 g of material, grinding, sieving to -100 mesh, and regrinding, until all the material is sieved to -100 mesh. Mix this sample well by covering tightly and shaking. To analyze weigh out 4.00 grams and proceed as for marine life, making final volume to 100 ml.

Appendix 3-II: Sample Analysis by X-Ray Spectrometry

Sample Preparation

Pulverize sample to minus 100 mesh using suitable apparatus. (A Torsion Blance Co. mortar grinder was used in the work described.) By weighing directly into a plastic vial (2 inches long by 1 inch diameter) make dilutions of 5, 10, and 20% with prepared borax for a total weight of 3.5 to 4 grams. (Borax is prepared by adding approximately 0.4 grams of Cab-O-Sil to 100 grams of reagent grade sodium tetraborate powder. After thorough mixing the powder is passed through a 100 mesh screen and stored in an air-tight bottle. This procedure renders the borax free-flowing and promotes homogeneous mixing with the sample). Empty the contents of the vial into a 1 1/4 inch diameter die and press into a pellet at 30,000 psi.

Sample Analysis

Center the diluted residue pellet in the sample holder and place the assembly in the x-ray chamber. Activate the tungsten target tube at 50 KV and 35 MA. Set the goniometer at the appropriate angle for the most intense line of the metal sought using the lithium fluoride analyzing crystal. Fill the optical path with helium and obtain at least three counts for averaging. Count a blank borax pellet and a standard for efficiency determination. On all samples also obtain counts at the tungsten L-alpha peak. A correction is then made for the density of the pellet as indicated by the height of the reflected tungsten peak. The result for each metal in counts per second is multiplied by the ratio of counts per second of tungsten in the blank to cps of tungsten in the sample. This figure minus the counts per second of the metal in the blank pellet gives the net cps. After correction for counting efficiency, the parts per million of the metal in the diluted ash may be obtained from a curve constructed from standards prepared in the same way. This figure divided by the dilution of ash in the pellet gives the final result in terms of ppm of metal in the original ash. The average of the three dilutions is used, unless there is evidence of matrix absorption at high dilution or lack of sensitivity at low dilution.

Appendix 3-III: Preparation of Artificial Sea Water (Cl = 19.00%)

Compound	Grams
NaCl	23.477
$MgCl_2$	4.981
Na_2SO_4	3.917
$CaCl_2$	1.102
KCl	0.664
$NaHCO_3$	0.192
KBr	0.096
H_3BO_3	0.026
$SrCl_2$	0.024
NaF	0.003

Make to 1000 ml with distilled water. After aeration the pH should be between 7.9 and 8.3.

From: Lyman and Fleming, J. Marine Research, 3:134 (1940)

Appendix 3-IV: Determination of Phosphates in Incinerator Residue

A. Sample Preparation

1. Water Soluble. Weigh 2 grams residue into 150 ml beaker. Add 20 ml demineralized water, place on magnetic stirrer hot plate and heat at just below boiling for 1 hour. Filter through Whatman No. 40 filter paper into 50 ml volumetric flask, and bring to volume. Carry through blank. Take 25 ml aliquot for analysis.

2. Acid Soluble. Weigh 0.2 gram residue into 50 ml beaker. Add 5 ml of acid mixture of concentrated HCl and HNO_3 and demineralized water at 1:1:1 ratio. Heat on hot plate at just below boiling for 1 hour. Evaporate to dryness (do not Bake). Add to residue 25 ml of 1 N H_2SO_4 and again heat for 1 hour. Filter through Whatman No. 40 filter paper into a 100 ml volumetric flask and bring to volume with demineralized water. Carry through blank. Take 3.0 ml aliquot for analysis.

B. Sample Analysis

Pipet sample aliquot into 125 ml separatory funnel and add, if necessary, appropriate volume of demineralized water to bring to 25 ml. Pipet 12 ml of solvent mixture and 7.5 ml molybdate solution. Shake mixture for 1 minute and allow 20 minutes for layers to separate. Drain off water layer and pipet 12 ml of alcoholic H_2SO_4 and 1 ml fresh $SnCl_2$ solution into solvent solution; swirl and drain through phase separation paper into stoppered flask. Determine absorbance against demineralized water at 625 mμ after 10 minutes and before 30 minutes.

C. Reagents

Solvent mixture: Mix equal volumes of reagent grade toluene and isobutanol.

Molybdate solution: Cautiously add 55 ml H_2SO_4 to about 200 ml distilled water and cool. Weigh out 25 g $(NH_4)_6Mo_7O_{24}\cdot 4H_2O$ and dissolve in 200 ml distilled water. Add the cooled H_2SO_4 mixture and make up to 500 ml.

Alcoholic H_2SO_4: Cautiously add 20 ml H_2SO_4 to 980 ml of reagent grade methanol with mixing.

$SnCl_2$ solution: Weigh out 0.2 g $SnCl_2\cdot 2H_2O$. Add 1 ml conc. HCl and 17 ml 6N H_2SO_4. Make up to 100 ml. Prepare fresh daily.

PO_4^{-3} standards: Dissolve 0.3583 g dried KH_2PO_4 in distilled water and dilute to 500 ml (1 ml = 500 μg PO_4^{-3}). Dilute 2 ml of this solution to 100 for working standard of 10μg PO_4^{-3}/ ml. Use standards of 1.0 to 70 μg (0.1 to 7 ml) for standard curve.

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TOXICITY OF INCINERATOR RESIDUES FOR MARINE ORGANISMS

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TOXICITY OF INCINERATOR RESIDUES FOR MARINE ORGANISMS

I. BIOASSAYS

Candace Oviatt

A. Introduction

Incinerator Residue

The residues used in these studies were obtained from the Boston, Massachusetts municipal incinerator where household, institutional, and commercial refuse is burned. Mainly, the residue used in the biological studies consisted of particles less than 12 mm in diameter, a size that represented about 45% of the total residue discharged from the incinerator. The remaining 55% of the residue was principally tin cans, bottle fragments, large metal objects, and rocks. Dry, hot residue (unquenched) was obtained directly from the incinerator hoppers and passed through a 12 mm mesh sieve to provide this component. The chemical and physical nature of this residue was discussed in Section 3.

Particle roundness, determined according to the method of Powers (1) is shown in Table 4-1. For every size classification, material categorized as "very angular" represented the highest percentage and as size decreased, the percentage of "very angular" increased.

Terms:

Total Residue: All the non-segregated components of incinerated solid waste as discharged from the incinerator.

Whole Residue: That unquenched component of total residue which passed through a 12 mm mesh screening. This component was about 45% of total residue.

Sieved Residue: That unquenched component of total residue which

TABLE 4-1

Roundness of Incinerator Residue Particles

(% of particles counted in each size group)

	8mm	4mm	2mm	1mm	0.5mm	.125mm	less than .062mm
Very Angular	34.5	49.6	49.0	54.6	68.5	62.3	78.5
Angular	29.1	35.6	27.5	26.3	23.8	31.9	18.7
Subangular	27.1	13.6	11.2	13.1	7.0	5.3	2.1
Subrounded	7.4	1.1	8.6	4.7	0.4	0.5	1.6
Rounded	1.5	--	2.6	0.9	--	--	--
Well Rounded	0.5	--	0.4	0.4	--	--	--
Number	203	185	233	236	214	188	187

passed through 1 mm mesh screening.

Finely Divided Residue: That component of total residue which passed through 0.062 mm mesh sieve. This component **was about** 5% of whole residue.

Residue Extract: The sea water component of whole residue soaked for usually 24 hours in sea water and then filtered through a glass wool pad. Concentrations were made by weight of extract to weight of dilutant.

Washed Residue: The whole residue component of whole residue soaked for usually 24 hours in sea water and dewatered by filtering the sea water through a glass wool pad.

Methods

Standard Methods for the Examination of Water and Waste Water (1962)[2] lists aquatic bioassay procedures for use in evaluating toxicity of wastes and other water pollutants. Two constraints of the routine bioassay method are 1) there must not be an excessive oxygen demand associated with the material to be tested and 2) the test substance must be relatively stable and non-volatile. Tests on the oxygen demand of the incinerator residue indicated that 5.6% of residue by weight was required to remove 50% of the oxygen present in sea water at 15C and most of the oxygen removed appeared to be taken up within the first 24 hours. This degree of oxygen demand was not considered excessive. As the residue had been subjected to high heat in the burning process, it was assumed to be reasonably stable and non-volatile and no tests were required to confirm these properties.

The bioassay procedure consisted of exposing marine animal species to graduated concentrations of residue for 24, 48, 96, and 168 hours. Residue concentrations of 1, 1.8, 3.2, 5.6 and 10% by weight with sea water were used in 76 l aquaria in association with control aquaria of identical size except with no residue. Oxygen was added to each tank through air stones and during warm weather, a refrigerator unit controlled temperature in each aquarium to 11C ± 2C. After the test animals were introduced, oxygen concentration, pH, conductivity and temperature were monitored periodically. The median tolerance limit (TLM) i.e., the concentration of the tested material in sea water at which 50% of test animals can survive for specific exposure periods was used as the measure of acute toxicity.

Advantages of this bioassay procedure are:

1) It is a simple, fast procedure. All that is required is water in which the animals can live, the residue to be evaluated, and test organisms. Ample sea water supplies (averaging 30 ppt) were available at the wet laboratory of the Rhode Island State Marine Fisheries Section, where these experiments were carried out, and test organisms were gathered in local waters of Wickford Harbor and the west passage of Narragansett Bay by periodic seining and bottom trawling expeditions.

2) The natural unfiltered sea water and test animals were similar to those which would be found at the site of a large scale dumping operation.

Limitations of the bioassay procedure are:

1) For the bioassay procedure to have the greatest value, the test organism should be the most sensitive likely to be present

at the residue dumping site. In these experiments a wide variety of species with representatives of several phyla were chosen and special emphasis was placed on economically important species. Although it is not possible to state that the species most sensitive to residue were selected, a special effort was made to seek those likely to be most sensitive on the basis of their known characteristics and life cycle.

2) Laboratory assay is limited in the extent it can duplicate conditions in natural waters and experimental requirements for reproducibility and prescribed confidence levels necessitate stabilization of many variables which normally fluctuate in natural waters. In nature, toxicants have more opportunities to react with or become complexed with an enormous variety of organic and inorganic materials normally present in water and bottom surfaces and microbiological decomposition may alter substances, to produce new products of greater or less toxicity.(3)

3) The length of time an assay can be conducted under controlled conditions depends upon how well experimental factors may be controlled and the purpose for which the data will be used(3) whereas dumping operations at a site may continue for many years and over many animal life cycles. Therefore, bioassays extending only to 10 day periods are inadequate to demonstrate long-term or chronic effects caused by contact with incinerator residue. These bioassay tests simulate most closely the effects of a single application of residue at a dumping site but are useful for demonstrating acute toxicity effects when they can be induced experimentally. The results of exposing selected

species to incinerator residue for long periods are discussed in Part II of this section.

4) As incinerator residue is a non-homogeneous mixture, more complete chemical and physical analyses of the residues used in each experiment might have been useful in interpreting the variability in bioassay results encountered in some experiments.

B. Results of Bioassays

Whole Residue Bioassays

1) Winter flounder (Juvenile) (*Pseudopleuronectes americanus Walbum*.

The results of bioassays on juvenile winter flounder are summarized in Tables 4-2, 4-3, and 4-4 and Figures 4-1 and 4-2. A probit analysis was carried out on whole residue (less than 12 mm) and sieved residue (less than 1 mm)(4). The median tolerance levels (TLM) for these analyses were found to be as follows (Figures 4-1 and 4-2 and Table 4-2):

	Concentration
24 hour exposure to whole residue	greater than 10%
10 day exposure to whole residue	greater than 10%
24 hour exposure to sieved residue	7.3%
10 day exposure to sieved residue	2.1%

The smaller particules of sieved residue were more toxic than whole residue and this toxicity increased over the 10 day period. (In this connection see also part IV of this Section.

TABLE 4-2

Probit Analyses on Winter Flounder (Pseudopleuronectes americanus) Bioassays in Whole Residue (less than 12 mm) and Sieved Residue (less than 1mm)(4)

Level of Stimulus Log$_{10}$ % Residue Concentration X	Number of Animals Tested n	Number of Animals Responding r	Proportion of Animals Responding p = r/n	Z_p+5 Y'	Y	Equation of the line of Relationship Y=5+b(X-μ)
24 Hour Bioassays -- Winter Flounder in Whole Residue (less than 12 mm)						
0	70	0	0	0	1.7	Y=3.35X+1.45
.255	100	2	0.02	2.95	2.5	
.505	100	8	0.08	3.59	3.3	μ = 1.0
.748	80	23	0.413	4.77	4.2	
1.0	60	20	0.333	4.56	5.0	
10 Day Bioassays -- Winter Flounder in Whole Residue						
0	55	8	.145	3.94	3.7	Y=1.07X+3.87
.255	45	4	.089	3.66	4.0	
.505	65	11	.169	4.05	4.3	μ = 1.05
.748	55	19	.345	4.60	4.6	
1.0	45	19	.423	4.80	4.8	
24 Hour Bioassays -- Winter Flounder in Sieved Residue (less than 1 mm						
0	45	0	0	0	0	Y=8.1X-1.95
.255	10	0	0	0	0	
.505	20	0	0	0	2	μ = .86
.748	35	18	.514	5.03	4.2	
1.0	25	19	.760	5.71	6.0	
10 Day Bioassays -- Winter Flounder in Sieved Residue						
0	35	6	.17	4.05	2.9	Y=5.6X+3.14
.255	10	4	.40	4.75	4.3	
.505	20	10	.50	5.00	5.7	μ = .33
.748	25	25	1.00	8.09	7.2	
1.0	15	15	1.00	8.09	8.5	

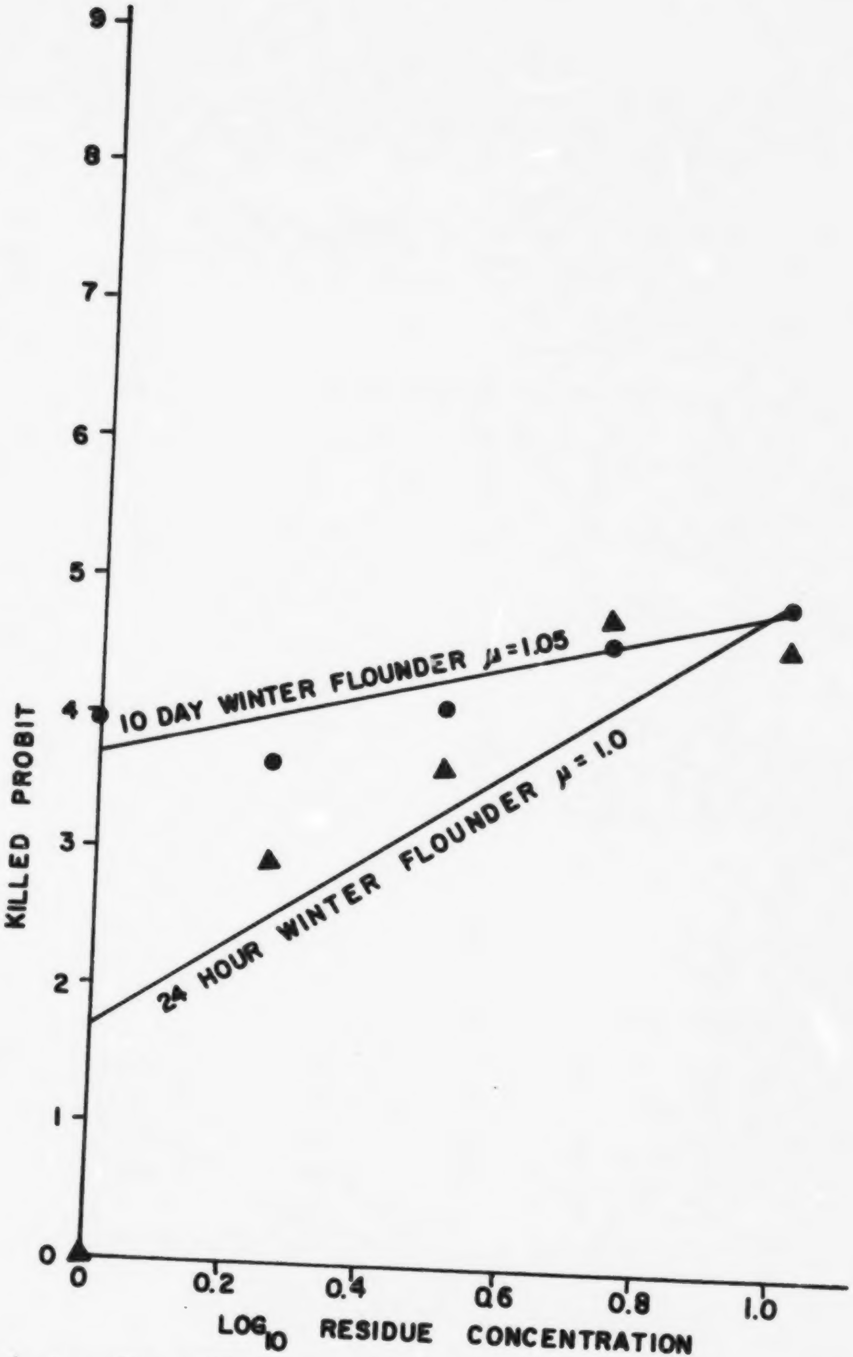

Figure 4-1. The effect of whole residue toxicity on winter flounder at 24 hours (▲) and 10 days (●).

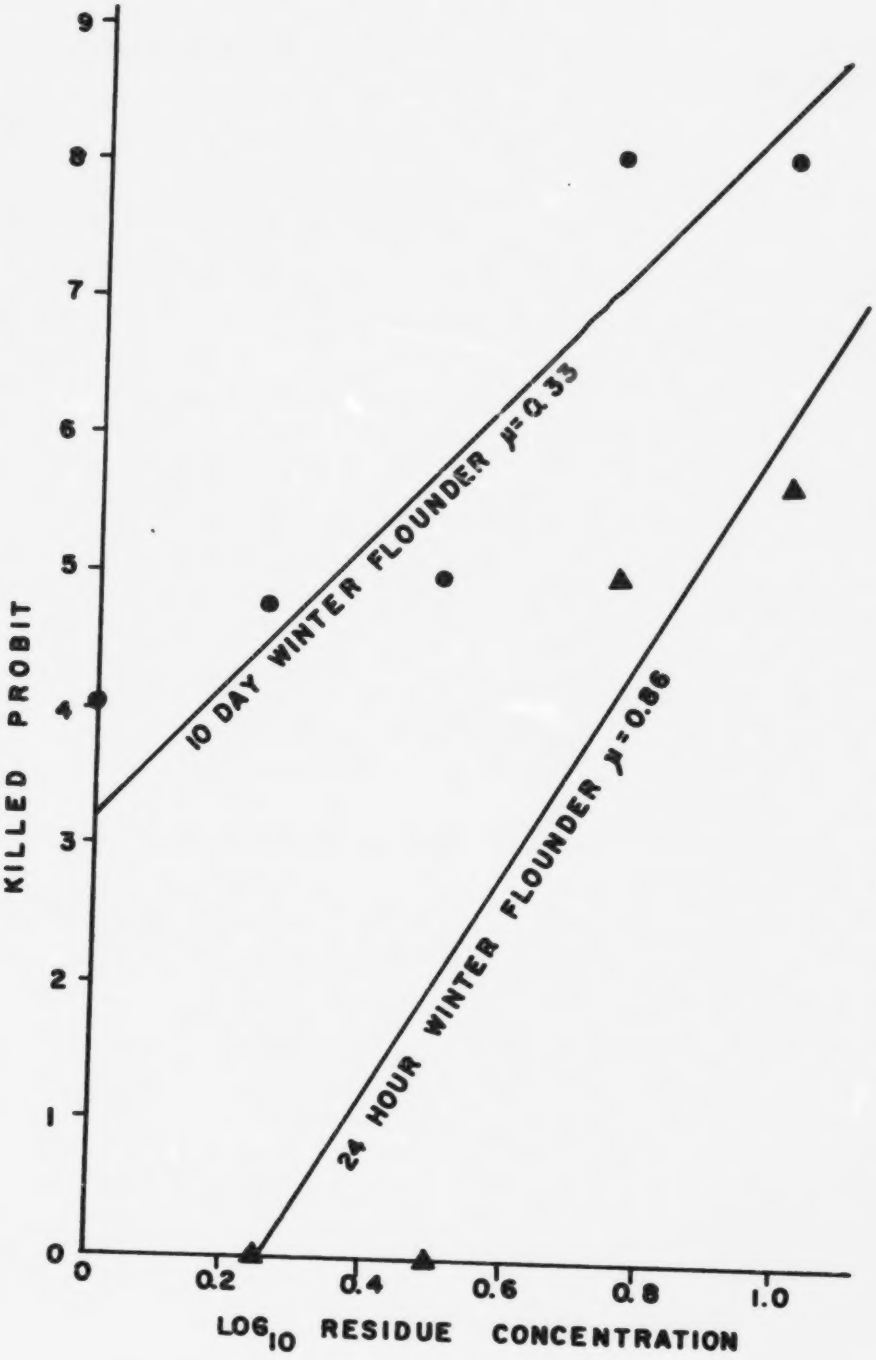

Figure 4-2. The effect of sieved residue toxicity on winter flounder at 24 hours (▲) and 10 days (●).

Table 4-3: Bioassays on Winter Flounder (*Pseudopleuronectes americanus*) with Residue Components.

			Percent Survival				
			Residue Concentration (by weight)				
Experiment	Days	Control	1%	1.8%	3.2%	5.6%	10%
Bioassays with Residue Extract Made by Soaking Whole Residue in Sea Water for 24 Hours.							
1	1	100	---	---	---	100	100
	2	100	---	---	---	90	60
	4	100	---	---	---	70	60
2	1	100	---	100	100	100	100
	9	90	---	100	70	70	90
3	1	100	---	100	90	100	100
4	1	100	---	---	---	---	100
	2	100	---	---	---	---	100
	4	100	---	---	---	---	100
	10	100	---	---	---	---	100
Bioassays With Extracted Residue Made by Soaking Whole Residue in Sea Water for 24 Hours.							
1	1	100	---	---	---	---	90
	2	100	---	---	---	---	90
	4	100	---	---	---	---	90
	10	100	---	---	---	---	90
2	1	100	100	100	100	100	100
	2	100	100	100	100	100	100
	4	100	100	100	100	100	100
	10	100	100	100	100	100	100
3	1	100	100	100	100	100	100
	2	100	100	100	100	100	100
	4	100	100	100	100	100	100
	10	100	100	100	100	100	73.4*

* O_2 Out of Adjustment: 2.5 ppm O_2

Table 4-4: Bioassays on Winter Flounder (Psuedopleuronectes americanus) with Settled Whole and Sieved Residue

			Percent Survival			
			Residue Concentration			
Experiment	Days	Control	1.8%	3.2%	5.6%	10%
Bioassays -- Whole Residue Allowed to settle for 24 hours.						
1	1	100	100	100	100	100
	2	100	100	100	100	100
	4	100	100	100	100	100
	10	100	100	100	100	100
Bioassay -- Sieved Residue Allowed to Settle for 24 Hours.						
1	1	100	---	---	---	10
	2	100	---	---	---	0
Bioassay -- Sieved Residue Allowed to Settle for 72 Hours.						
	1	100	---	---	---	100
	2	100	---	---	---	100
	4	100	---	---	---	100
	10	100	---	---	---	90

Bioassays with residue extract and extracted residue (Table 4-3) indicated high survival although some variability was encountered with residue extract. Bioassays with residue which was allowed to settle indicated (Table 4-4) excellent survival when the settling period was long enough (i.e., >24 hours).

These results are interpreted to mean that small (less than 1 mm) suspended particles were the main cause of mortality of winter flounder. (See part IV this Section).

2) Sea Scallop (Placopecten magellanicus Gmelin)

The results of bioassays on sea scallops are summarized in Table 4-5 and Figures 4-3 and 4-4. A probit analysis was carried out on whole residue and on residue extract made by soaking whole residue in sea water for 24 hours. The TLM levels determined by these analyses were as follows:

	Concentration
24 hour exposure to whole residue	greater than 10%
10 day exposure to whole residue	2.2%
96 hour exposure to residue extract	greater than 10%
10 day exposure to whole residue extract	2.7%

Residue extract, prepared by soaking whole residue in sea water for 24 hours, was separated from residue particles by filtering through glass wool but this procedure left the extract noticeably cloudy. Survival of scallops was always higher when they were able to clear the water by their own processes.

A clear interpretation of the results appears doubtful. Two possibilities present themselves. Either the sea scallop is susceptible to low concentrations of small suspended particles or to some soluble toxic component of the residue.

Other Species - Bioassays

A limited number of bioassays were carried out on several other species. The results can be summarized as follows:

1. Quahaug (Mercenaria mercenaria Linnaeus): No mortality occurred in whole residue concentrations up to 10% for 90 days.

2. Common Mummichog (Fundulus heteroclitus Linnaeus): No mortality occurred in whole residue concentrations up to 30% for 60 days.

3. Shrimp (Palaemonetes vulgaris Say): High mortalities occurred at whole residue concentrations above 5.6%.

4. Sand shrimp (Crago septemspinosus Say): No significant mortalities occurred at whole residue concentrations below 1.8%.

5. Juvenile menhaden (Brevoortia tyrannus Latrobe): High mortalities occurred during the first 24 hours at most concentrations. However, no mortality occurred after the first 24 hours at concentrations up to 10%.

6. Adult lobster (Homarus americanus Milne-Edwards): No mortality at concentrations up to 10% for 10 days.

7. Lobster larvae (Homarus americanus Milne-Edwards): Fourth stage lobster larvae died rapidly in control and treatment tanks. However, no mortality due to whole residue concentrations up to 5.6% alone could be detected.

8. Juvenile Millet (Mugil cephalus Linnaeus): No significant mortality in whole residue concentrations below 3.2%.

TABLE 4-5

A Probit Analysis on Sea Scallop (Placopecten magellanicus), Bioassays in Whole Residue and Residue Extract

Level of Stimulus Log_{10} % Residue Concentration %	Number of Animals Tested n	Number of Animals Responding r	Proportion of Animals Responding p = r/n	Z_p+5 Y'	Y	Relationship Y=5+b(Y-μ)
24 Hour Bioassays -- Sea Scallop in Whole Residue (less than 12 mm)						
0	40	0	0	0	0	Y=5.4X-9.4
.255	20	0	0	0	0.7	
.505	40	1	.025	3.03	2.0	μ = 1.10
.748	40	3	.075	3.55	3.3	
1.	40	7	.175	4.06	4.7	
10 Day Bioassay - Sea Scallop in Whole Residue						
0	40	7	.175	4.06	3.5	Y=55X +3.13
.255	20	1	.05	3.36	4.4	
.505	40	17	.425	4.31	5.8	μ = 0.34
.748	40	40	1.00	8.09	7.3	
1.	40	40	1.00	8.09	8.5	
96* Hour Bioassay - Sea Scallop in Residue Extract Made by Soaking Whole Residue for 24 Hours						
0	80	8	.10	3.72	2.4	Y=2.4X+2.22
.255	80	0	0	0	2.9	
.505	80	14	.175	4.06	3.4	μ = 1.15
.748	80	15	.188	4.12	4.1	
1.0	80	17	.213	4.19	4.7	
10 Day Bioassay - Sea Scallop in Residue Extract						
0	80	25	.312	4.50	4.1	Y=2X+4.13
.255	80	6	.075	3.55	4.6	
.505	80	47	.587	5.23	5.1	μ = 0.43
.748	80	60	.750	5.67	5.7	
1.0	60	52	.867	6.11	6.1	

*Insignificant mortality at 24 hours.

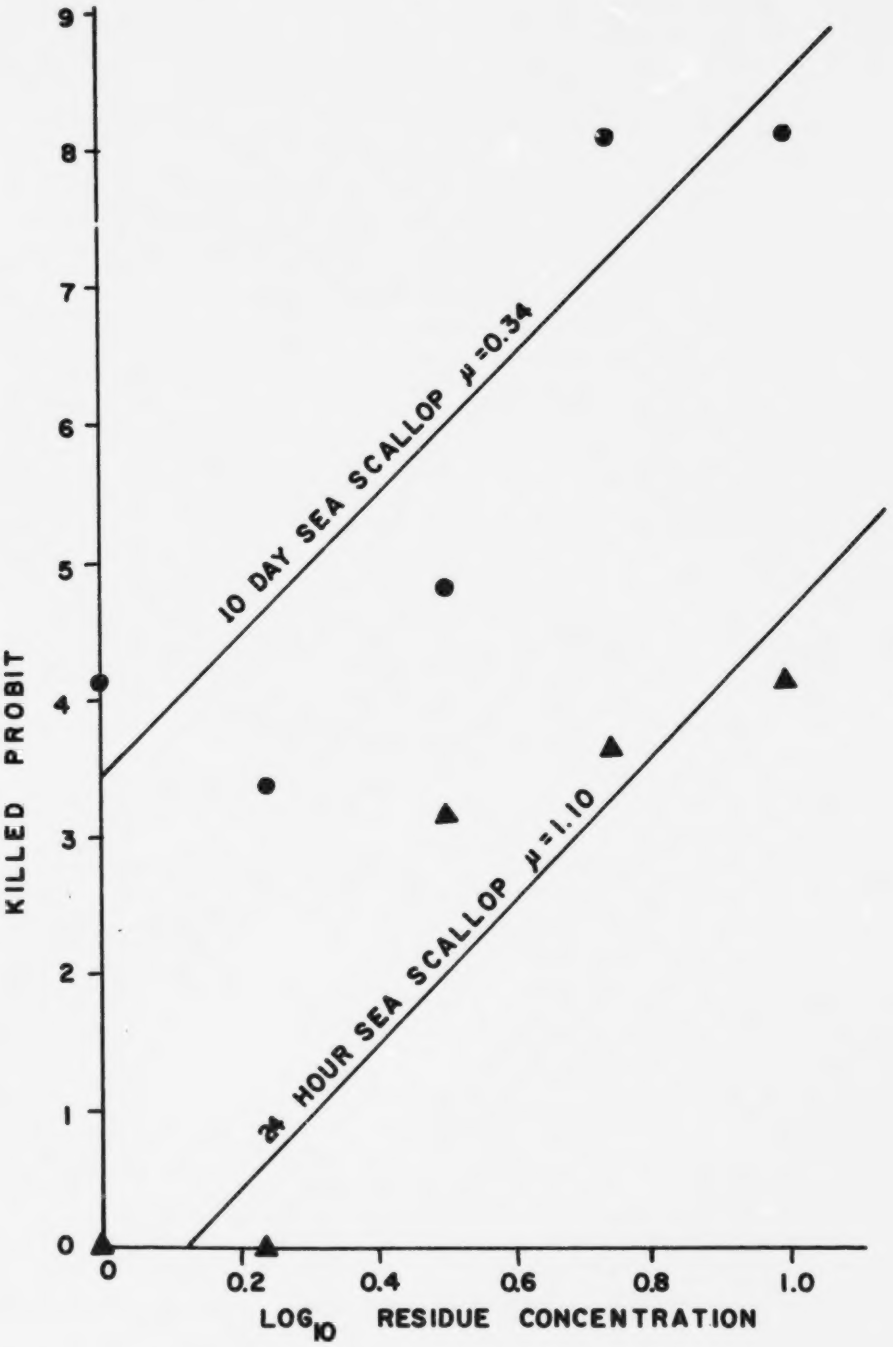

Figure 4-3. The effects of whole residue toxicity on sea scallops after 24 hours (▲) and 10 days (●).

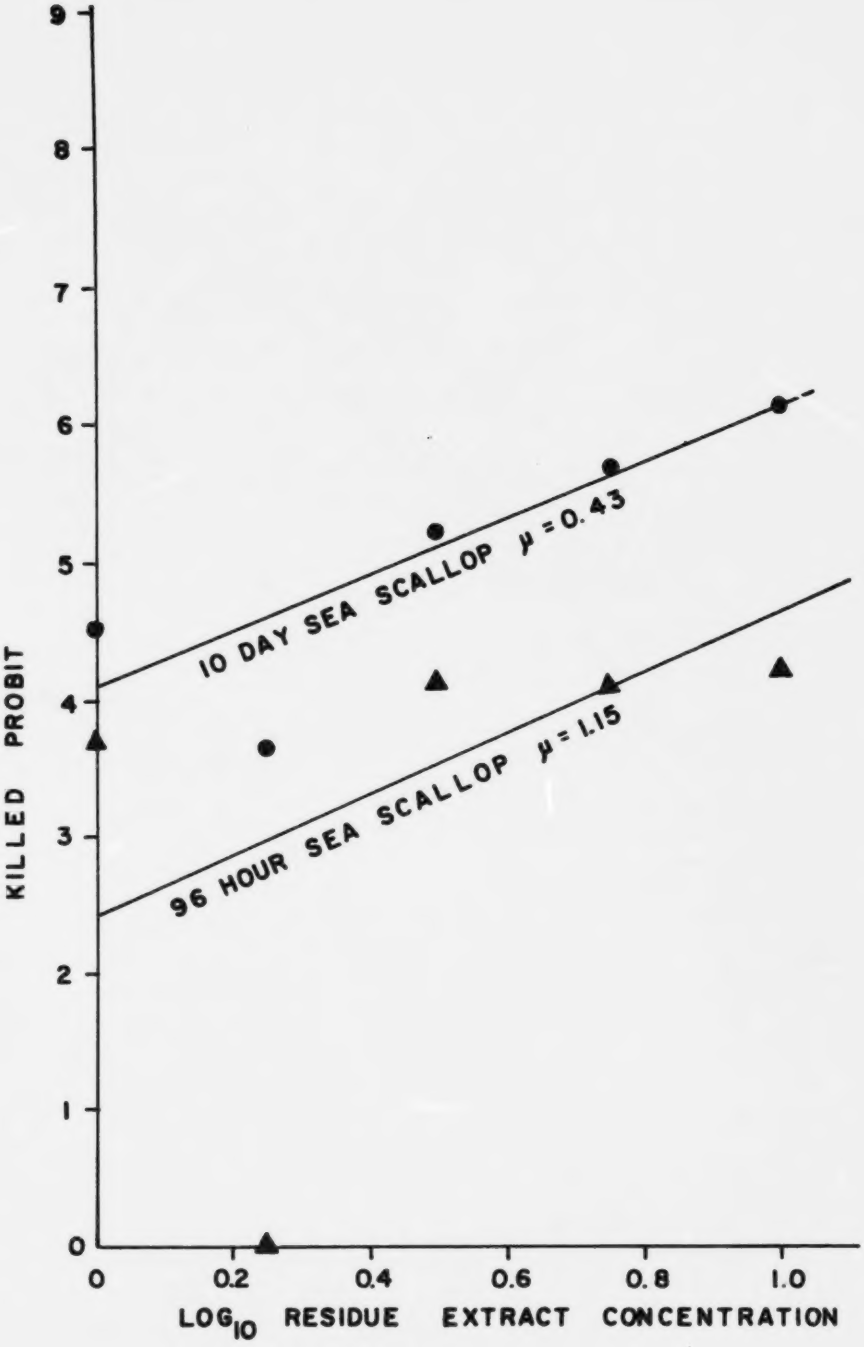

Figure 4-4. The effects of whole residue extract toxicity on sea scallops after 96 hours (▲) and 10 days (●).

II. LONG PERIOD IN SITU ASSAYS

Candace Oviatt

A. Introduction

The environment may be used as an assay medium to overcome some of the limitations of the laboratory approach and to investigate growth rates and survival over long time periods at concentrations much lower than the median tolerance limits established in bioassay experiments. Therefore, experiments were carried out in field plots to study chronic effects resulting from frequent periodic applications of residue over time periods of months and years. The three species employed for long period exposures in Wickford Harbor were hard shell clams, *Mercenaria mercenaria*, winter flounder, *Pseudopleuronectes americanus*, and sea scallops, *Placopecten magellanicus*.

B. Results

1) Hard Shell Clam (*Mercenaria mercenaria*)

Residue treatment was carried out on hard shell clams for up to 37 months in outside plots. Whole incinerator residue was dumped on these animals twice weekly in amounts equal to and double the amounts that would be discharged by a single large incinerator ship operating daily with municipal refuse.

A group of three circular experimental pens were constructed in Wickford Harbor of such size that each pen enclosed 9.3 m^2 (100 ft^2) of sediment. The pens were constructed of 1.3 cm wire mesh imbedded into the sediment with about 20 cm extending upward into the water. The area in which the clam pens were located was exposed 3 to 4 times a year during neap tides. Pen A, the low exposure pen, was treated with 2 lb of residue twice weekly. Center Pen B acted as a control and received no residue. Pen C, the high exposure pen, received 4 lb of residue twice weekly. The weighed residue was slurried with sea water in a plastic bucket and dumped acress the treated plot from a skiff.

In August 1965, 150 marked, measured and weighed animals were put into each pen. In May, 1966, an additional 150 animals were marked, measured, weighed and placed in each pen. These animals were recaptured, counted, and measured in October 1966 and replaced in their same plots. One hundred additional animals were added to each plot in June 1967. All animals were recovered, counted, and measured in October 1967 and again replaced. In September, 1968, all remaining animals were recovered, counted and measured for the last time. The planting and recovery schedule is summarized in Table 4-6 along with the number of living animals, dead animals, and empty shells recovered each time.

As a rule, the most animals were recovered from the low residue treatment plot and the least from the control plot. The greatest mortality, as indicated by empty shells, occurred in the control plot in the fall of the first and third years and from the low residue plot during the second year. Very few empty shells were recovered from the high treatment plot.

The percentage of animals recovered at each measurement period over the total 37 month period is shown in Table 4-7. Many factors influenced recovery:

TABLE 4-6

Episodes in Procedure During Long Term Growth and Survival Whole Residue Assay on the Hard Shell Clam or Quahaug

(*Mercenaria mercenaria*)

	Pen A Treatment: 2 lbs. of residue twice a week	Pen B: Control	Pen C Treatment: 4 lbs. of residue twice a week	Comments
August 1965				
Addition of Animals	150	150	150	
May 1966				
Addition of Animals	150	150	150	Heavy algae growth during August 1965
October 1966				Sediment Analysis 8/24/66, Analysis of Variance.
Recapture & Measurement	193	179	184	
Dead: Empty Shells	52	82	5	
June 1967				
Addition of Animals	100	100	100	
October 1967				
Recapture & Measurement	302	246	229	
Dead: Empty Shells	21	8	2	
Unidentified	32	38	48	
Outsiders	20	5	8	
Individuals Placed Out In: 1965	87	50	59	
1966	90	75	74	
1967	93	83	48	
September 1968				
Recapture & Measurement	187	42	169	
Dead: Empty Shells	21	99	5	Heavy algae growth during August 1968
Unidentified	33	2	66	
Outsiders	81	8	4	Outside Quahaugs accidentally transplanted into Pen A
Individuals Placed Out In: 1965	58	7	57	
1966	57	14	66	Rao(5) growth comparison
1967	61	21	38	

(a) The recovery effort may have been different between the plots. Although an effort was made to spend the same amount of time on each plot, different heights of tide on successive recovery days and different personnel may have introduced variability into the recovery effort. In addition, since it took several days to measure all the animals, some were necessarily held longer than others and the longer the animals were held the less legible their identifying marks became.

(b) Seasonal changes had a considerable effect on the numbers of animals recovered from each plot. During winter, ice would form at a low tide and enclose many animals. When ice was carried out of the plot area by wind and currents, these animals would be carried with it. During the late summer, mats of algae (largely *Enteromorphia*) grew over the plots and when the algae died, some clams were poisoned and only their empty shells would be left behind.

(c) Predation had an effect on the number of animals and the number of empty shells. Sea gulls removed their victims from the area. Other predators, such as drills, moon snails, and starfish left the empty shells of the victim behind.

(d) The high residue treatment may have had the effect of burying the animals. These factors make correlations between months of treatment and percent recovery complex. Seasonal changes had the greatest effect on the control plot. Ice completely destroyed the perimeter of this pen and some animals were found tens of feet from it. The other pens were less severely affected. During the summer, dying algae were associated with more dead

TABLE 4-7

PERCENT OF HARD SHELL CLAMS RECOVERED FROM HIGH TREATMENT, CONTROL AND LOW TREATMENT PLOTS

	Percent recovered			Percent empty shells			Percent missing		
	High	Control	Low	High	Control	Low	High	Control	Low
5 months (May '66-Oct. '66)	81	79	66.0	0	7	2.0	19	15	42.0
5 months (June '67-Oct.'67)	48	83	93	*	*	*			
14 months (Aug.'65-Oct.'66)	37	22	52	1	37	16	62	41	34
16 months (June '67-Sept.'68)	38	21	61	1	25	17	61	54	22
17 months (May '66-Oct.'67)	49	50	60	*	*	*			
26 months (Aug.'65-Oct.'67)	39	33	58	*	*	*			
28 months (May '66-Sept.'68)	44	9	38	0	31	9	56	60	53
37 months (Aug.'65-Sept.'68)	38	5	39	3	12	8	59	83	53

* not noted

clams in the control plot than in the others. Predation effects appeared to be heaviest on the low treatment and control plots. Many of the empty shells from these plots contained holes made by drills or moon snails. The few starfish that were observed in the area probably affected all plots equally and this was probably true for sea gulls as well.

Residue additions coarsened the natural silt-clay sediment of both the low and high treatment plots. A sediment analysis made after one year of residue treatment showed that the fraction of material over 2 mm in size was proportional to the amount of residue added, as shown below:

Location	Sediment greater than 2 mm (% by wt.)
1. Low treatment plot	
a. Plot center	24
b. Plot edge	4
2. Control plot	
a. Plot center	6
b. Plot edge	8
3. High treatment plot	
a. Plot center	32
b. Plot edge	10

The beneficial effect of greater sediment porosity may have been the reason for the higher survival observed in the treated plots during summer when algae died. The coarser texture may have permitted greater water penetration through the sediment and thereby counteracted the reducing conditions produced by the dead algae.

Growth tests.

Average initial weights and shell diameters of recovered animals are shown in Table 4-8. Although randomly selected, it appears that with three exceptions the smallest clams were placed in the high treatment plot, the medium sized clams were placed in the low treatment plot, the largest clams were placed in the control plot. These three exceptions were the 5 month interval between June 1967 and October 1967, the 16 month interval between June 1967 and September 1968, and the 28 month interval between May 1966 and September 1968. During these three periods the smallest clams were in the low treatment plot whereas the largest clams were again in the control plot. Therefore, observed differences in growth may have been due to a difference in the size of the animals in each plot. However, hard shell clams from 5 to 50-60 mm shell diameter seem to have a fairly constant growth rate in Rhode Island waters(6) and all of the clams that were used had average shell diameters less than 50 mm.

Average weight and shell diameter increases per year for all three plots are presented in Table 4-9. Although size increases were corrected to yearly rates of growth, the rates are variable within the plots. This degree of variability can be explained largely by the fact that the animals were placed out at different months of the year and growth of clams in Rhode Island waters occurs only during the summer months(6). Therefore, animals placed out in May grew faster than those placed

TABLE 4-8

AVERAGE INITIAL WEIGHTS AND SHELL WIDTHS OF HARD SHELL CLAMS SUBJECTED TO RESIDUE TREATMENTS

	Average Initial Weight			Average Initial Shell Width		
	High	Control	Low	High	Control	Low
5 months (May '66-Oct.'66)	9.7	14.6	11.5	25	29	28
5 months (June '67-Oct.'67)	60.5	64.9	43.9	46	44	41
14 months (Aug.'65-Oct.'66)	10.9	21.4	19.5	31	40	38
16 months (June '67-Sept.'68)	51.6	53.3	43.0	43	43	41
17 months (May '66-Oct.'67)	11.6	18.1	12.1	26	31	27
26 months (Aug.'65-Oct.'67)	12.9	19.8	18.7	33	37	38
28 months (May '66-Sept.'68)	12.5	17.9	11.8	26	29	26
37 months (Aug.'65-Sept.'68)	11.0	23.5	16.1	31	39	36

TABLE 4-9

YEARLY RATE OF WEIGHT AND SHELL DIAMETER INCREASES OF HARD SHELL CLAMS SUBJECTED TO RESIDUE TREATMENT

	Average Weight Increase/Year			Average Shell Diameter Increase/Year		
	High gm	Control gm	Low gm	High mm	Control mm	Low mm
5 months (May '66-Oct.'66)	24.0	19.4	20.6	17.0	11.5	14.9
5 months (June '67-Oct.'67)	20.2	16.3	19.0	4.8	4.1	5.8
14 months (Aug.'65-Oct.'66)	18.5	9.8	14.8	7.9	3.3	5.1
16 months (June '67-Sept.'68)	11.2	13.4	9.6	3.7	3.2	4.5
17 months (May '66-Oct.'67)	16.2	13.0	14.3	9.1	4.6	8.3
26 months (Aug.'65-Oct.'67)	23.4	10.7	11.8	6.4	1.2	3.0
28 months (May '66-Sept.'68)	14.1	8.5	11.9	7.3	4.7	5.5
37 months (Aug.'65-Sept.'68)	16.7	7.1	11.4	5.3	1.5	2.9

out in January and June clams appeared to grow faster than those placed out in August.

Growth was greatest in the high residue treatment plots, and least in the control plot with two exceptions. These exceptions were the 5 month interval from June 1967 to October 1967 and the 16 month interval from June 1967 to September 1968. This pattern and exceptions show marked similarity with the pattern of initial sizes and exceptions.

Despite some evidence to the contrary it appeared possible that small clams grew faster to produce the observed growth increase pattern. To resolve this question, a Rao growth rate comparison test(5) was used. This test indicated that greater growth occurred in clams exposed for 37 months in the high residue plot. No difference in growth between the plots occurred for animals exposed for 28 months. Thus, residue treatment did not reduce growth rates and can, in some cases, be correlated with greater growth rate.

It seems reasonable to expect that if small clams grow faster they should show greater growth rates in whichever pen they are placed if the residue treatment has no detrimental effect. Therefore, in the 5 month interval from June 1967 to October 1967, low treatment animals should have grown fastest because they contained the smallest clams. Although shell diameter increase was greatest, weight increase was only medium, whereas the other two rates followed the initial size patterns. In the 16 month interval from June 1967 to September 1968, the low treatment clams should have grown fastest but results were equivocal in that the shell diameter increase was greatest but weight increase was medium, whereas high treatment clams which initially had medium weight, had a medium rate of growth. In the 28 month interval between May 1966 and September 1968, low treatment clams should have had the greatest growth and control clams the least growth on the basis of absolute clam size but results were ambiguous, i.e., the low treatment clams had only a medium increase in shell size and weight whereas least growth occurred in the control clams and most growth in the high residue treated clam. In this case, the prevalent growth pattern was reestablished even though the initial size pattern was exceptional. Although the evidence is not conclusive, the exceptions suggest that factors other than initial size influenced growth rates.

An analysis of variance (ANOV) test was performed on the October 1966 recaptures to determine whether growth rates between plots were significantly different. Average size changes were as follows:

	Average Weight Increase 1965 Individuals 14 months	Average Shell Increase 1965 Individuals 14 months
Single dose,Pen A	17.34 gm	5.9 mm
Control, Pen B	11.36 gm	3.9 mm
Double dose, Pen C	21.61 gm	9.2 mm
	1966 Individuals 5 months	1966 Individuals 5 months
Single dose, Pen A	8.58 gm	6.2 mm
Control, Pen B	8.05 gm	4.8 mm
Double dose, Pen C	10.00 gm	7.1 mm

These data were subjected to a one-way analysis of variance test for samples of unequal size according to Snedecor(7). The weight and shell diameter increases for animals treated for 14 months and the weight and shell diameter increases for animals treated for 5 months were tested as shown in Table 4-10. In each case, least growth was found in the control plot; more growth was found in the low residue plot; and greatest growth was found in the high residue treatment plot. These differences in

TABLE 4-10

ANALYSES OF VARIANCE FOR UNEQUAL SAMPLE SIZES ON HARD SHELL CLAMS EXPOSED TO HIGH AND LOW INCINERATOR RESIDUE TREATMENTS TWICE A WEEK FOR A 5 MONTH PERIOD AND A 14 MONTH PERIOD

Source of Variation	d.f.	SS	MS	F	F.05	F.01
14 Month Clam Weight Increase						
Total	165	15,923.12				
Plots	2	2,196.08	1,098.04	13.03**		4.75
n	163	13,727.04	84.21			
14 Month Clam Shell Diameter Increase						
Total	112	2,096.3				
Plots	2	706.7	353.3	27.97**	3.09	4.83
n	110	1,389.6	12.63			
5 Month Weight Increase						
Total	300	7,845.49				
Plots	2	211.25	105.62	4.12*	3.03	4.68
n	298	7,634.24	25.61			
5 Month Clam Shell Diameter Increase						
Total	299	1,976.82				
Plots	2	257.3	128.65	22.25**	3.03	4.68
n	297	1,719.52	5.78			

* Significance at the .05 level of confidence.

** Significance at the .01 level of confidence.

growth were statistically significant at the .05 level of confidence for the 5 month weight increase test and at the .01 level of confidence for the other 3 tests. Growth was significantly greater in the residue treatment plots than in the control plots.

A Rao growth rate comparison(5) designed to test for real differences between growth rates of individual animals which have been subjected to different treatments was performed on the 1968 growth measurements. The experimental design involves noting initial weight of several marked organisms and their successive growth increments over time.

The assumptions of this test are:

(1) regression lines for all samples are parallel

(2) regression lines are linear

(3) variance about the regression lines is equal

(4) distribution of individual growth rates is essentially normal initially.

Three F tests are included in the growth comparison: F_1, a test of the null hypothesis that the mean initial measures of growth are similar for all samples, resolves the question of whether or not the initial differences in weight are significant; F_2 tests the null hypothesis that the regression coefficients are similar for all samples; and F_3 tests the null hypothesis that the values of growth rate adjusted for initial measure of growth are similar for all samples.

One Rao growth rate comparison test was performed on animals which had been treated since August 1965 and which were from the high and low treatment plots (Not enough animals were recovered to include measurements on control animals). Another growth rate comparison test was performed on animals which had been treated since May 1966. Both groups of data met the assumptions of the test before being transformed and after transformation as shown in Table 4-11. The 37 month hard shell clam growth rate comparison (F_3) indicated significantly greater growth in the high residue treatment plot than in the low residue treatment plot at the .01 level of confidence. The regression lines for the 28 month hard shell clam growth rate comparison, shown in Figure 4-5, indicate least growth in the control, more growth in the low treatment, and most growth in the high treatment group. However, these differences were not statistically different, as shown in Table 4-11. Initial weight differences (F_1 test) were never significant and the regression coefficients (F_2 test) were similar in all tests.

For 1965 animals, higher residue treatment was correlated was significantly greater growth rate whereas for 1966 animals, growth rates were not significantly greater for high treatment, low treatment, and controls. These conflicting results indicate that residue treatment is in no way determental to hard shell clam growth rates and in some cases residue treatment can be correlated with a greater growth rate. The experimental plots had a natural silt clay sediment which the residue treatment coarsened. A possible explanation for the greater growth of the 1965 animals from the high residue treatment plot may be the fact that hard shell clams grow faster in sand than in mud.(8)

TABLE 4-11

RAO (1958) GROWTH RATE COMPARISONS OF HARD SHELL CLAMS
SUBJECTED TO INCINERATOR RESIDUE TREATMENTS

		4 lb Pen A	Pen B	2 lb Pen C
Test I. Number		19	---	33
Interval:	1965-1968			
Transformation:	None			
F_1	: 1.14			
F_2	: 2.50			
F_3	: 7.69**	F.05 4.04, F.01 7.19		
Regression		Y = -.03X + 36.1		Y = .07X + 28.7
Test II. Number		19	---	33
Interval:	1965-1968			
Transformation:	Log-Log (n+25)			
F_1	: 0.97			
F_2	: 1.92			
F_3	: 7.57**	F.05 4.04, F.01 7.19		
Regression		Log(Y+25) = -.06 Log(X+25) + 1.3		Log(Y+25) = .02 Log(X+25) + .81
Test III. Number		31	9	35
Interval:	1966-1968			
Transformation:	None			
F_1	: 1.13	F.05 3.13, F.01 4.92		
F_2	: 0.19			
F_3	: 2.89			
Regression		A Y = .07X + 21.7	B Y = -.07X + 17.3	C Y = -.01X + 19.6
Test IV. Number		31	9	35
Interval:	1966-1968			
Transformation:	Log-Log (n+25)			
F_1	: 1.10			
F_2	: 0.71			
F_3	: 1.58			
Regression		Log(Y+25) = .021 Log(X+25) + 2.8	Log(Y+25) = -.02 log(X+25) + 2.8	Log(Y+25) = .01 log(X+25) + 2.8

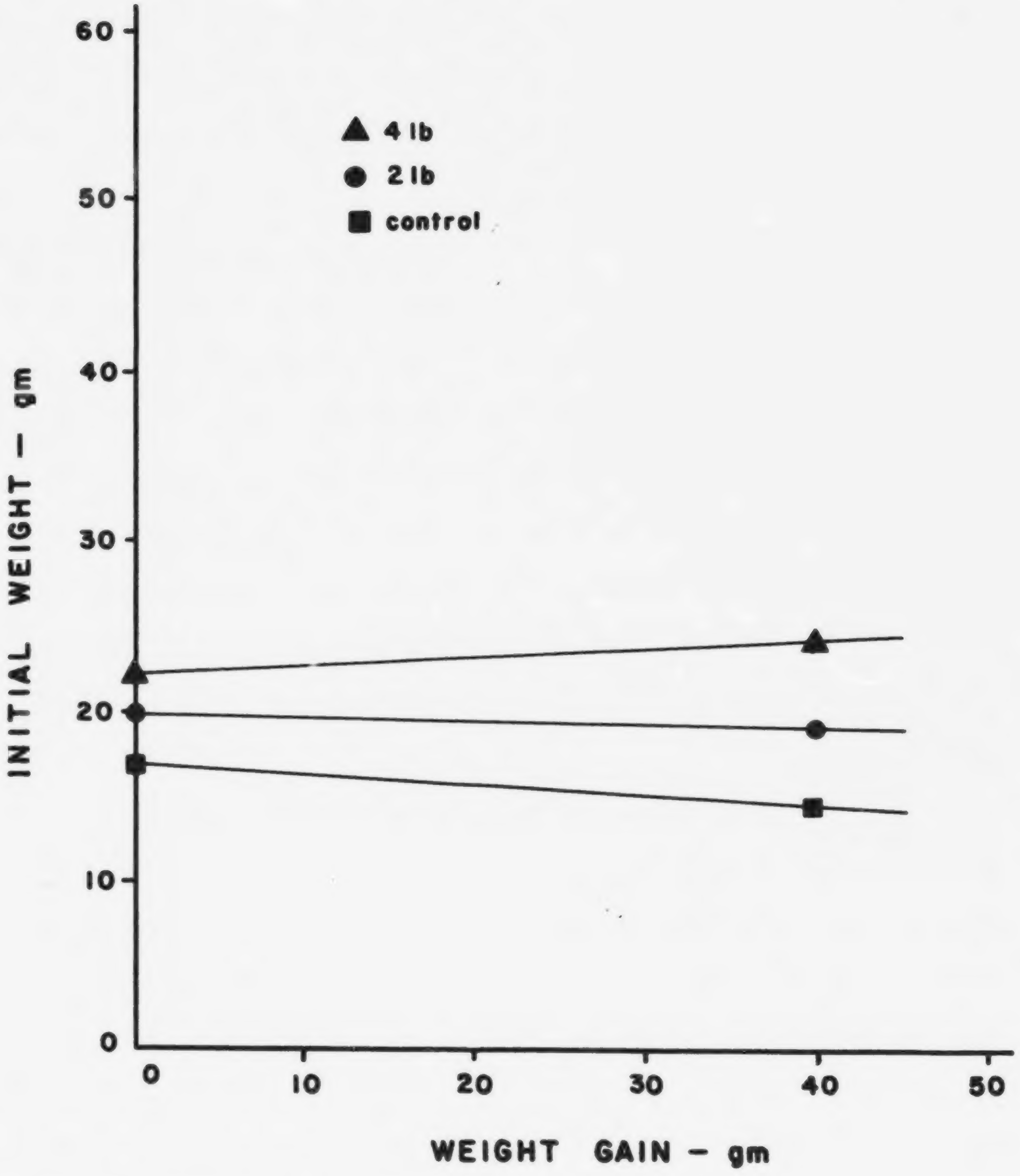

Figure 4-5. Rao (1958) growth comparison of hard shell clam weight increase, 1960-1968.

Inhibition of growth occurs in silt-clay and may result from interruption of feeding and additional expenditure of energy occasioned by the necessity for frequent cleaning of the animal's filtering apparatus(9).

2) Winter Flounder (Pseudopleuronectes americanus)

A total of six long term assays were conducted with winter flounder. The longest of these experiments lasted seven months and the shortest lasted about one month. Little success was experienced in keeping experimentally induced mortality low even though the experimental design was constantly modified. Mainly, these experiments were plagued by re-occurring infections. Nevertheless, control, low residue, and high residue treatment pens were evenly subjected to these sources of mortality in all experiments.

Three 9.3 m^2 circular pens were constructed of 2.54 cm^2 plastic coated hardward cloth. Two batches of individually tagged, measured, and weighed winter flounders were placed in these pens; the first batch, 25 fish per pen, was entered in August 1965 and the second, 21 fish per pen, was entered on November 2, 1965. The schedule of treatment was for pen A to receive 2 pounds of whole residue, pen B, no residue, and pen C, 4 pounds of residue each Tuesday and Friday. The fish were fed quahaug meat once a week.

Recoveries of fish were made between December 3 and 7, 1965 because it was feared that ice would destroy the pens if they were left through the winter. Results, shown in Table 4-12, indicate that 46% of the fish from control pen B, 30% of the fish

TABLE 4-12

Winter Flounder (*Pseudopleuronectes americanus*)
Recaptures from Residue Treated Field Pens - 1965

Pen A -- Low Treatment

Beginning Month	Start	End December	Percentage	Total Time	Average Size Change, TL	Weight
August	25	4	16	4 mos	-0.1 cm	
November	21	9	43	1 mos		
TOTAL,	46	14	30		-0.1 cm	-2.84 gm

Pen B -- Control

Beginning Month						
August	23	8	35	4 mos		
November	21	12	55	1 mo.		
TOTAL	44	20	46		0	+5.68 gm

Pen C -- High Treatment

Beginning Month						
August	25	1	4	4 mos		
November	21	0	0	1 mo.		
TOTAL	46	1	2		0	-16.8

from pen A, and 2% of the fish from pen C were recaptured. Differences in length and weight for all pens were considered insignificant since they did not exceed the accuracy of the measuring devices.

Factors other than the residue treatment accounted for the recapture percentages. In pen A, two fish were killed and lost during recaptures. One of the recaptures was dying of infection and two fish got caught in the wire mesh of the pen and died. In pen B, one fish died in the wire mesh before recapture and after the recapture attempt, a fish died in the wire mesh. From pen C, one tagged fish was caught by a fisherman indicating escape from this pen. Growth increases were least in the control plot, greater in the low residue treatment plot, and most in the high residue treatment plot. An analysis of variance test indicated these differences were statistically significant. However, the sizes of the animals when first placed in the plots showed a pattern of largest animals in the control plot, medium animals in the low residue treatment plot, and smallest animals in the high residue treatment plot.

Although fish in all pens were equally exposed to disease, mortality due to trap configuration, unsuccessful recapture and escape, more fish were recaptured from the control pen than the others and the pen with lower residue treatment had more fish than the one with higher residue treatment. These results suggest that residue had an injurious effect on winter flounder held in outside pens although this conclusion was not supported by growth differences in the specimens recovered.

A similar experiment was conducted between March 1966 and and November 1966. This time,23% of the fish were recovered from pen A, 24% were recovered from pen B, and 23% from pen C. Size changes could not be determined because the fish, with few exceptions, had lost their tags. Some of the flounders subjected to 7 months of ash treatment were sacrificed to determine if the treatment had changed fatty acid ratios as stored lipids are an important source of energy,and stresses induced by residue treatment might be indicated by the amounts and ratios of lipids present.

Fatty acids were analyzed by gas-liquid chromatography at the Narragansett Marine Laboratory by Dr. H. Perry Jefferies. Preparation of the tissues involved dissection, extraction, saponification,and methylation. Dissection of 2 control fish occurred on 1/17/67; 2 more controls and 2 high ash treatment fish were done on 1/19/67; and 2 additional controls and 2 additional high ash treatment fish were done on 1/20/67. A description of the flounder used in these studies in contained in Table 4-13. Lipids were extracted from homogenized and lyophized tissue with a solvent solution of chloroform, methanol, and water. Saponification of lipid residue was carried out in alcoholic potassium hydroxide by refluxing. The acidified sample was then methylated by refluxing and subjected to chromatographic analysis.

The percentage ratio of fatty acids in the testes of control fish and high ash treatment fish are compared in Table 4-14. The first number in column 1 is the fatty acid number of carbon atoms with the number of double bonds shown by the number after the colon. In both control and high ash treatment, a combined sample was made from two fish. Differences between the two sets of fish were small and, in most cases, less than 1%. These differences can be attributed to normal variability and it may be concluded that sexual development insofar as this characteristic can be indicated by fatty acid ratios, was similar in control and treated fish.

Comparisons of fatty acids in the livers of control and treated fish did not yield significant differences either, as shown in Table 4-15, i.e., the same acids in nearly the same percentages occurred in both sets of fish even though size, sex, and maturity differed widely. It may be concluded that fat storage was normal in the treated fish.

Fish from the second experiment were re-tagged, weighed, measured, and placed in three outside live-cars in November 1966. The live-cars measured 5'x10'x1.5' and were constructed from

Table 4-13. Description of Winter Flounder whose Tissues were used for Fatty acid Analysis

Flounder I
Immature female from the West Passage of Narragansett Bay
SL 22 cm
Wt. 210 gm
Liver wt. 4.7 gm

Flounder II
Mature male from the West Paggage of Narragansett Bay
SL 23 cm
Wt. 184 gm
Liver wt. 3.9 gm

Flounder III
Control #1352 Immature female
SL 20.5 cm
Wt. 160 gm
Liver wt. 1.2 gm

Flounder IV
High ash treatment #1370 Immature female
SL 20.5 cm
Wt. 132 gm
Liver 1.9 gm
Many intestinal parasites

Flounder V
Control #1371 Immature female
SL 22.5 cm
Wt. 172 gm
Liver wt. 3.2 gm

Flounder VI
High ash treatment #B0403 Ripe male
SL 30.3 cm
Wt. 130 gm
Liver wt. 2.1 gm

Flounder VII
High ash treatment #1393 Immature female
SL 20.3 gm
Wt. 197 gm
Liver wt. 2.0 gm

Flounder VIII
High ash treatment #B0424 Ripe male
SL 17.5 cm
Wt. 102 gm
Liver wt. 1.2 gm

Flounder IX
Control #1367 Ripe male
SL 22.8 cm
Wt. 168 gm
Liver wt. 2.3 gm

Flounder X
Control #1394 Immature male
SL 19 cm; wt. 115 gm; liver wt. 2.3 gm

Table 4-14 **Fatty acid Ratios Present in the Testes of Control and Ash Treated Winter Flounder.**

Fatty Acid	Testes - Percent Fatty Acids Control Flounders I & IX	 High Ash Treatment Flounders VI & VIII
12:1	0.1	0.15
14:0	0.8	0.9
14:1	0.8	0.4
16:0	17.4	22.3
16:1	4.8	5.9
18:0	3.5	2.4
18:1	27.9	26.1
18:2	2.3[c]	1.7[c]
20:1	3.7	2.8
22:1	4.9	3.6
20:5	8.4	8.9
22:3	2.5	2.3
24:1	1.0	1.0
24:2	4.3	4.9
22:6	12.9	12.6
26:1	4.5	3.8

Flounder I Testes wt. 30.46 gm
Flounder IX Testes wt. 16.62 gm
Flounder VI Testes wt. 9.15 gm
Flounder VIII Testes wt. 9.8 gm

c - contaminated

Table 4-15 Fatty acid Ratios Present in the Livers of Control and Ash Treated Winter Flounder.

Fatty Acid	Liver - Percent Fatty Acids									
	Control						Treated Fish			
	I	II	V	X	IX	x	VI	VII	VIII	x
14:0	1.5	1.9	2.0	2.2	4.1	2.3	4.0	2.9	2.8	3.2
14:1	0.9	2.0	0.4	0.3	0.4	0.8	0.7	0.4	0.6	0.6
16:0	26.3	15.4	19.2	20.6	30.3	22.4	24.[illegible]	20.0	25.0	23.3
16:1	8.7	15.8	8.1	15.4	7.4	11.1	7.7	12.2	10.6	6.1
18:0	3.6	0	3.6	2.4	4.8	2.9	4.6	3.4	4.4	4.1
18:1	16.4	23.2	14.6	21.0	11.8	17.5	18.5	12.5	11.6	14.2
18:2	1.5	1.2	1.8	0.5	1.5	1.3	1.4	1.4	2.3	1.7
20:1	1.9	5.7	3.7	3.9	2.0	3.4	3.8	3.1	3.3	3.4
22:1	5.5	1.5	5.7	5.0	6.0	4.7	3.7	5.6	7.3	5.6
20:5	14.6	11.9	10.4	7.6	10.2	10.9	12.0	10.2	10.4	10.9
22:3	1.6	3.0	2.7	2.1	3.3	2.6	1.8	1.9	2.2	2.0
24:1	1.3	0.5	1.9	1.2	2.1	1.4	1.5	1.3	1.1	1.3
24:2	2.9	4.0	1.9	1.2	1.9	2.3	2.8	1.9	2.6	2.4
22:6	10.3	10.9	14.7	8.5	10.5	10.5	9.6	19.1	10.4	13.0
26:1	1.8	2.3	3.5	2.4	3.3	2.7	2.1	2.1	2.2	2.2

1 inch mesh plastic coated hardware cloth. It was hoped that by placing them on the bottom, ice would not destroy them. In addition, 21 new fish were tagged, weighed, measured, and placed in each of the live-cars. This made a total of 36 fish in each car subjected to the bi-weekly residue treatment.

The fish were removed from the live-cars in January 1967, after two months exposure. Twenty percent were recaptured from pen A (low treatment), 25% from pen B (control), and 28% from pen C (high treatment). Fish were replaced in live-cars for treatment in March, 1967; 42 fish in pen A, 45 fish in pen B, and 41 fish in pen C. Through the summer and fall, an additional 41 fish were added to pen A, 40 fish to pen B, and 43 fish to pen C. During December 1967, 23% were recovered from pen A, 18% from pen B, and 19% from pen C. Fish lost weight in all pens and the amount of loss was similar in all pens. Weight changes of fish which did not lose their tags are shown in Figures 4-6, 4-7 and 4-8.

To check unexplained mortality, a long term winter flounder experiment was carried out inside the laboratory with untagged fish. Natural sea water entered a 375 gallon top tank (in which the controls were kept) at the rate of 16 gallon/min and then flowed to a bottom residue treated tank. Treatment was 1% whole residue (weight to water weight) and residue was renewed once a month. Ninety fish were placed in each tank at the beginning of the experiment and the animals were fed daily. During the first month, survival was equal in each tank, as shown in Table 4-16. After 7 months, 55% of the fish remained in the control

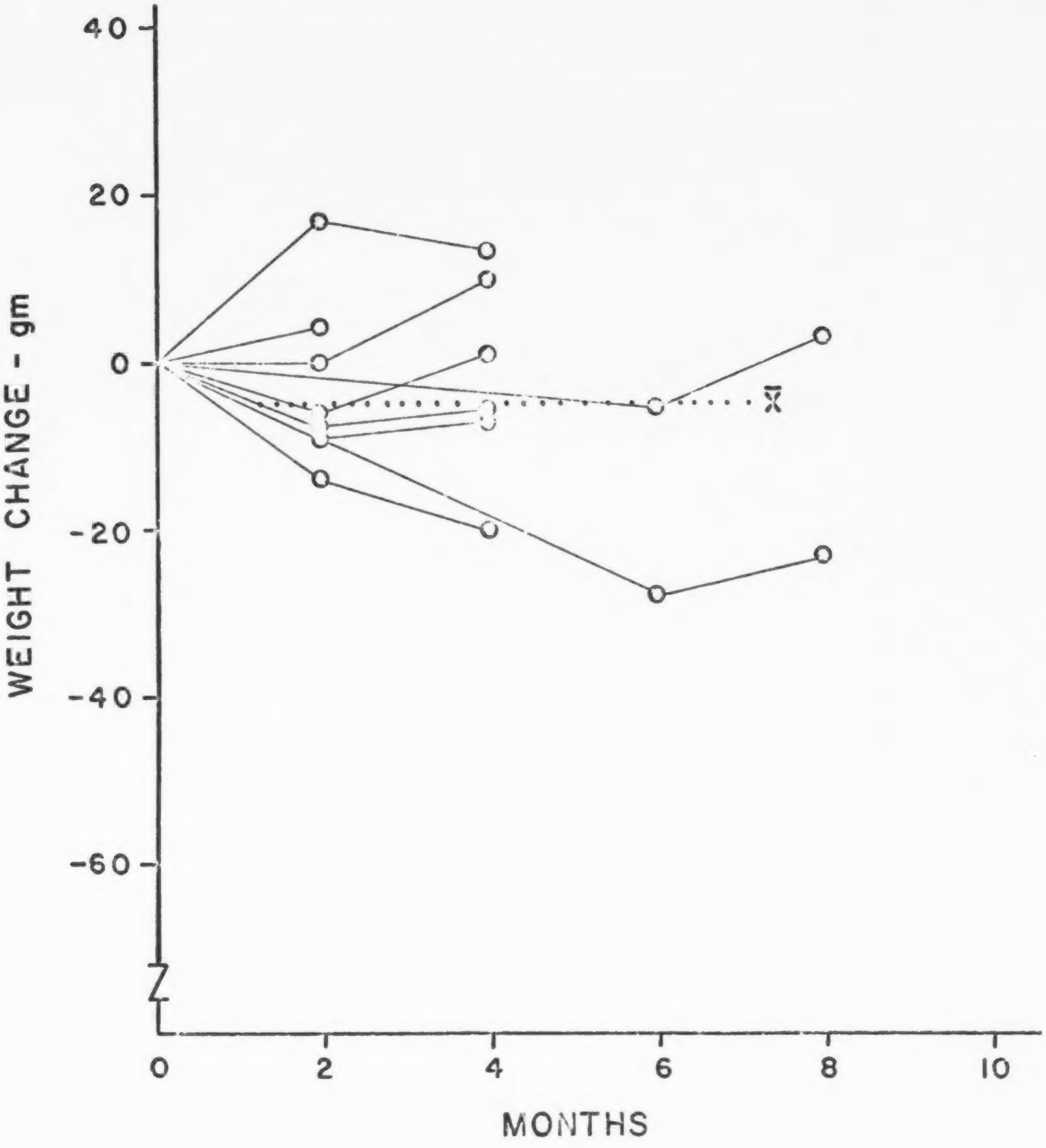

Figure 4-6. Weight changes of winter flounder during low residue treatment in outside pens. Note: mean value refers only to the first measurement interval.

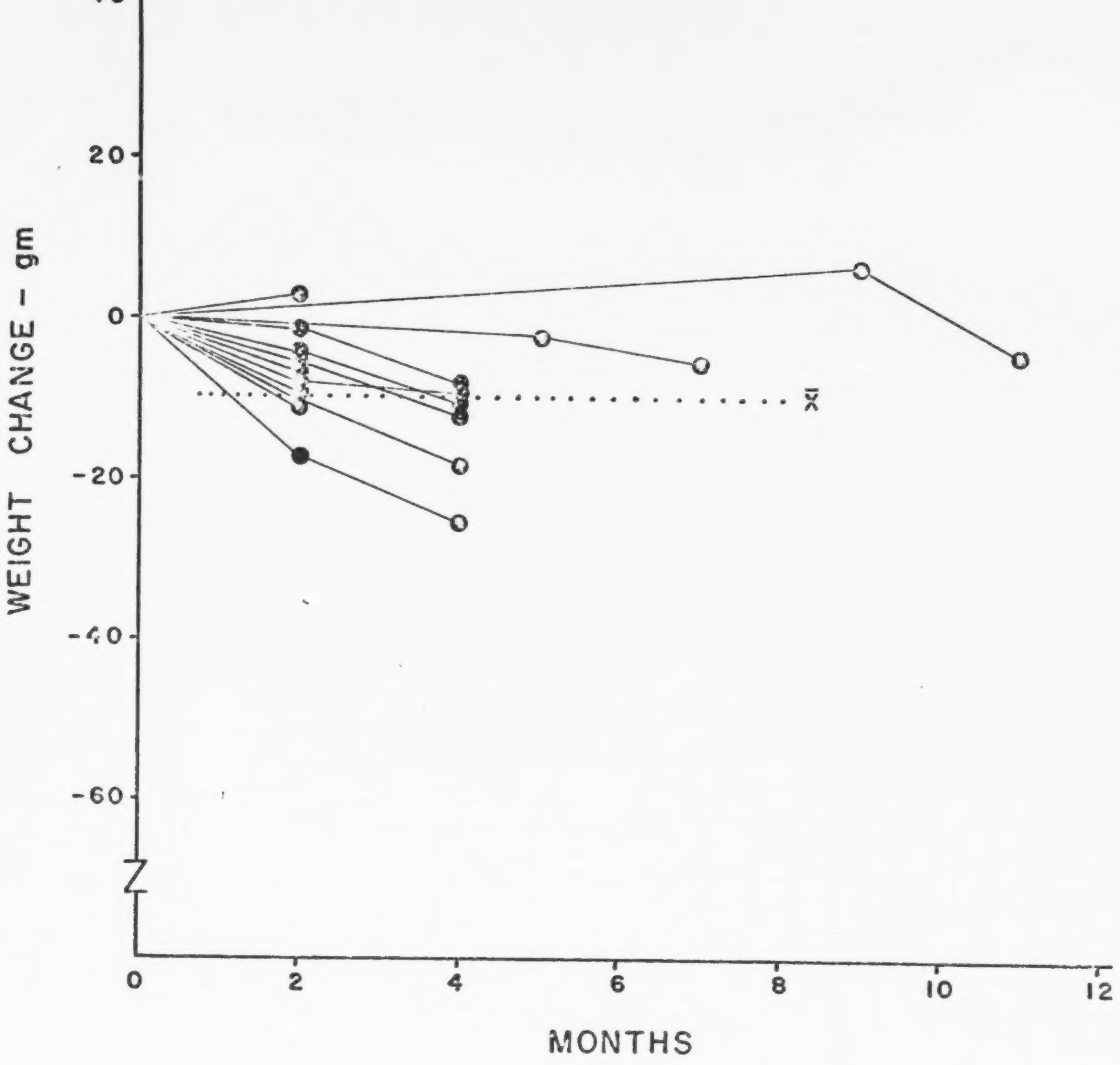

Figure 4-7. Weight changes of winter flounder during high residue treatment in outside pens. Note: mean value refers only to first measurement interval.

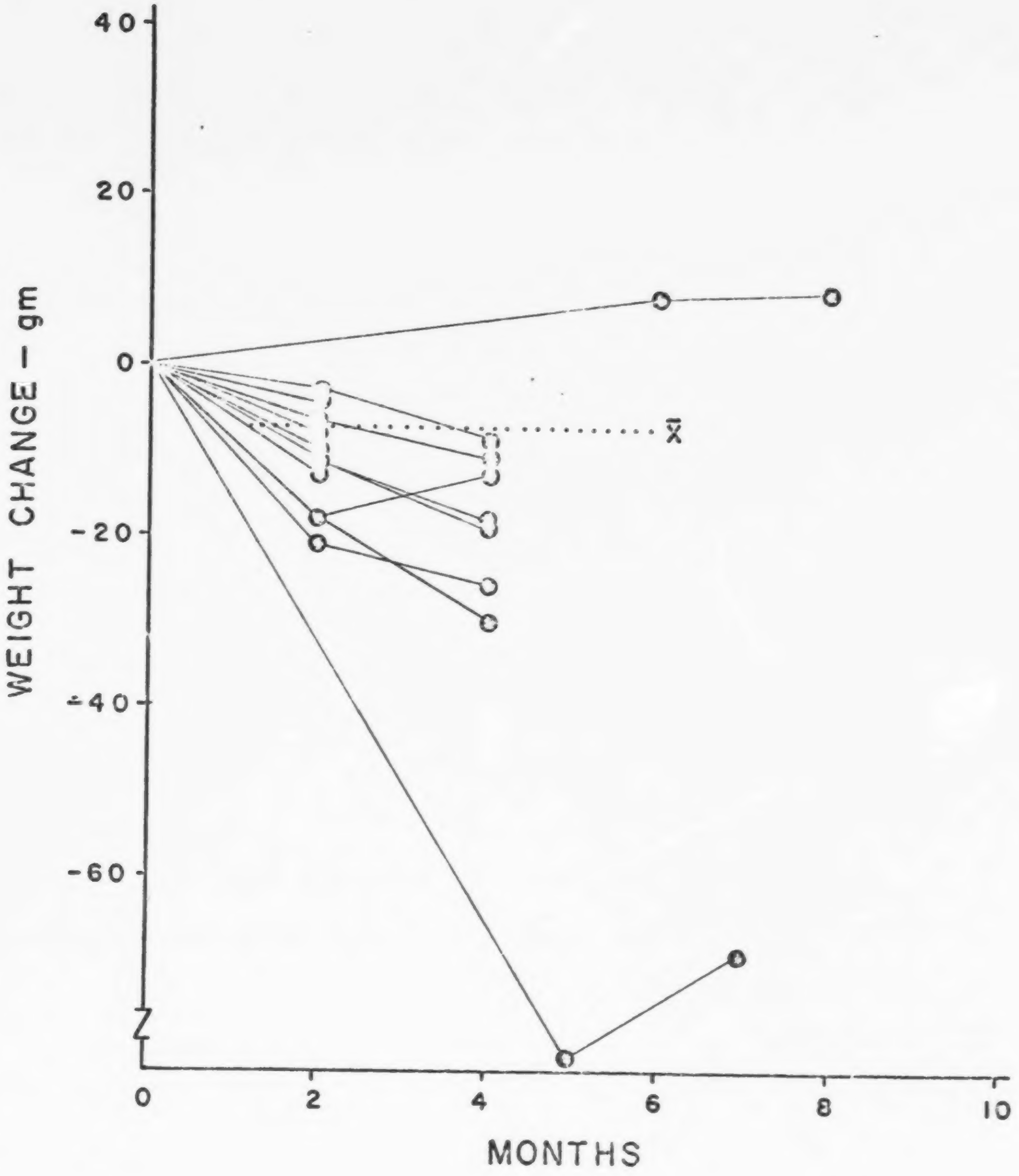

Figure 4-8. Weight changes of winter flounder controls in outside pens. Note: mean value refers only to the first measurement interval.

TABLE 4-16

SURVIVAL OF JUVENILE WINTER FLOUNDER DURING 7 MONTHS EXPOSURE TO A 1% WHOLE RESIDUE CONCENTRATION RENEWED MONTHLY IN AN OPEN SEA WATER SYSTEM

	Number of Fish		
	Control	Treated	
Number Beginning	90	90	
One Month	53	53	(20 fish removed from each tank for tissue analysis)
	33	33	
End -- 7 Months	18*	8**	

* One with sores; all the rest healthy.

** Five with ragged tails and fins; two with sores; 1 healthy.

tank but only 24% remained in the treated tank. All but one of the control fish were healthy whereas only 1 treated fish was healthy. The others had sores and ragged fins and tails.

Another long term experiment with juvenile winter flounder was carried out inside the laboratory in an open system with a 1% concentration by weight of incinerated cans. Sea water ran into a top control tank of 30 gallons capacity at a rate of 0.5 gpm and then into a treatment tank of 75 gallons capacity. Forty-five untagged fish were introduced into each tank at the beginning of the experiment. After 7 months, 9 fish remained in the control and 13 fish remained in the treatment tank.

Considerable mortality occurred during all the long term winter flounder experiments. Surviving fish tended to lose weight. Neither the mortality nor the weight loss could be attributed to the residue treatments since it was similar in all three pens. As far as can be determined, on the basis of all the experiments that were conducted, residue treatment had no effect on these fish. Observed mortality appeared to be due to re-occurring infections and the fact that many of the fish never learned to eat under their caged condition.

3. Sea Scallop

A long term inside experiment was carried out on tagged and weighed sea scallop in a divided 36 gallon tank. The water inlet side contained control animals and the water outlet side was treated with 0.82 lb of residue twice a week, an amount comparable to the exposure of the fish treatment pens treated at the higher dose rate. Sixty one scallops were placed in the treatment side and 59 in the control side. Nineteen additional animals were added after one month.

Mortality over a 4 month period is shown in Figure 4-9. Weights decreased markedly during the first two months of the experiment. Mortality and weight loss occurred similarly and without detectable differences to both treated and control animals. Water flow through the tanks was not sufficient to provide enough food for the animals and this combined with rising summer water temperatures produced starvation.

To reduce the effects of starvation, a long term inside experiment was carried out with fewer animals in larger tanks with faster seawater flow rates. Natural sea water flowed into a 375 gallon top control tank at a rate of 15.8 gallons/min and then to a 375 gallon bottom residue treated tank. The treatment was 1% whole residue concentration renewed once a month. Thirty-three untagged scallops were placed in each tank at the beginning of the experiment. After 3 months, 30 animals remained in the control tank and 31 animals remained in the treated tank. All were healthy. The residue treatment has no noticeable affect on the survival of these sea scallops.

Sediment Analysis of Outside Exposure Plots

After ash had been dumped on the harbor clam plots for one year and on the fish plots for three months, two core samples were taken from each on August 24, 1966. The procedures of analysis are summarized in Appendix 5-II of Section 5.

Results of the analyses are shown in Table 4-17. When the numbers are averaged and rounded off, the following facts became apparent:

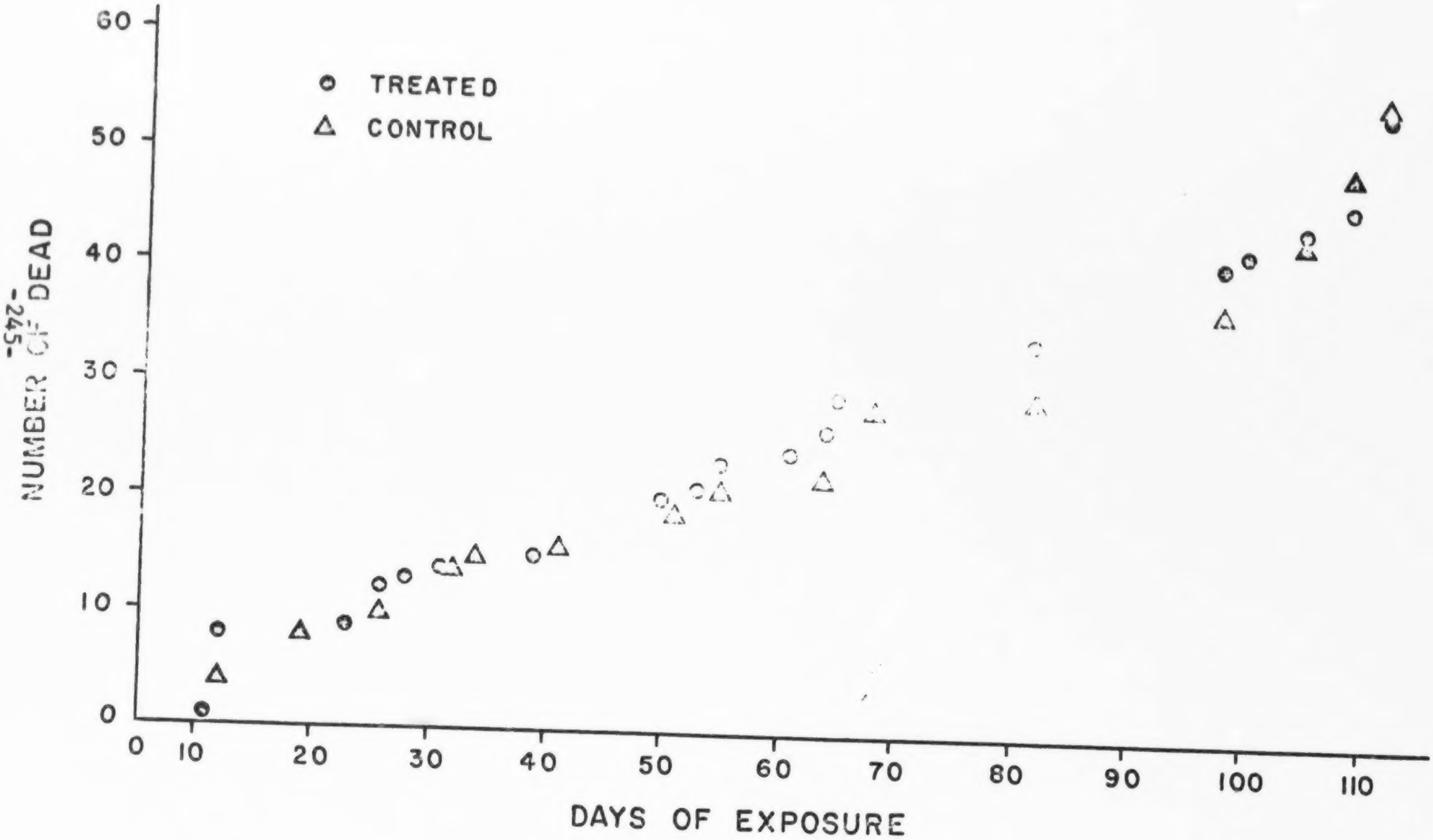

Figure 4-9. Mortality of control and high residue treated sea scallops.

Table 4-17. Analysis of Sediment Core Samples under Treated and Untreated Fish and Clam Exposure Plots
Samples taken 8/24

Sample Name	Greater than 2 mm gm	Less than 2 mm gm	pH	C	N	P	Cu	Mn	Fe
				ppm by weight					
Ash 1 2lbs Quahogs	24	184	6.95	1.92	.14	52.8	1.27	.88	27.7
Ash 1 2lbs Fish	44	217	7.62	1.43	.11	15.2	.93	1.18	31.5
Ash 1' 2lbs Fish	5	265	7.16	1.22	.09	8.0	.65	.05	20.6
Ash II Control Fish	1	175	7.02	1.17	.10	7.2	.50	.03	25.3
Ash III 4 lbs Quahogs	32	224	7.62	1.66	.12	6.4	.78	5.75	29.3
Ash II Control Quahogs	6	192	7.00	1.61	.12	26.4	1.03	.13	26.1
Ash III 4 lbs Fish	50	201	7.96	1.39	.10	28.0	1.83	2.45	31.5
Ash II Control Quahogs	8	229	6.92	1.30	.12	7.0	.65	.16	20.7
Ash 1' 2lbs Quahogs	4	214	6.75	1.67	.12	8.0	.9	.08	22.9
Ash II' Control Fish	2	223	6.70	1.30	.09	4.8	.75	.11	20.8
Ash 3' 4lbs Quahogs	10	205	6.90	1.76	.13	72.8	1.05	.21	23.3
Ash 3' 4lbs Fish	10	220	7.62	1.35	.10	13.2	1.20	1.18	24.9

1) The fraction of the sample over 2 mm was higher in the plots receiving more residue and was always greater in the treated plots than in the untreated controls. For reasons which are unclear, year old treated clam plots had less material over 2 mm than the three month old treated fish plots.

2) pH was close to neutral in all plots (i.e., 6.70 - 7.96).

3) Carbon was low and equal in the fish plots. Carbon was higher in the clam plots than the fish plots with the clam control plot having a slightly lower value than the exposed plots, which were equal.

4) Nitrogen was the same in all plots.

5) Phosphorus was always proportional to the amounts of residue deposited on the plot.

6) Copper was nearly the same in all plots.

7) Manganese was proportional to the residue quantity in the three fish plots and in two exposed clam plots but was abnormally high in the clam control plot. The reason for the latter observation is not known.

8) There were very similar values for iron in all the plots.

It may be concluded, therefore, that regular residue additions changed the normal sediment characteristics slightly. Evidently, the residue contributed larger particles to the sediment but if the values from the clam plots are valid, attrition also occurs. Carbon was found to be low in the bottom core samples, even though the carbon content of the residue was high. Perhaps, light carbon particles have a tendency to float off during the dumping process. With respect to plant nutrients, the residue probably contributes phosphorous to the environment but not nitrogen. With respect to toxic compounds, although the ash may be contributing a little manganese to the sediment, it is not in concentrations considered to be toxic to fish according to Duodoroff and Katz(10). Neither copper nor iron were added to the sediment from the residue.

In addition to making a sediment analysis, the quantity of residue that fell into the plots was determined. Samples were collected by placing a funnel with a surface area of 95 sq.cm. in the center of each plot 24 cm above the sediment surface. The samplers were left out for one month during which there were 8 additions of residue to the plots. The dry weights of the collected materials are shown in Table 4-18. The relatively large quantities of granular material collected over the control plots indicates considerable churning activity over the sediment surface (e.g., from tides, waves, and motor craft) and this tends to obscure the fraction of the samples caused by sediment additions alone. Residue was collected in significant amounts over the high treatment plots. When the amounts of sediment collected in the control plots are subtracted, the residue accumulation in the high treatment plots amounts to 0.6 lb residue/sq.ft. of bottom.

TABLE 4-18

DRY WEIGHT OF RESIDUE COLLECTED IN SEDIMENT TRAPS LOCATED IN EACH LONG-PERIOD EXPOSURE PEN

	Control gm	2-lb. Residue twice weekly gm	4-lb. Residue twice weekly gm
Fish Pens	45.4	38.9	65.6
Clam Pens	25.1	41.1	74.7

Notes: (1) Sediment traps exposed for a one month period (8 applications of residue).

(2) Pen area = 9.3 M^2; sediment trap area = 95 cm^2, i.e., approximately 1/1000th total pen area.

III. ADDITIONAL TESTS FOR INCINERATOR RESIDUE TOXICITY

Candace Oviatt

A. Introduction

Attempts were made to detect sub-lethal effects of residue by (1) comparing the reactions of treated and untreated fish to sound stimuli, (2) conducting comparative hatching and larval survival experiments and (3) observing the effects of the residue on the growth of three phytoplankton species to investigate influences on primary productivity.

B. Reaction times of *Fundulus heteroclitus*

A reaction timer was used to test for sub-lethal stresses caused by exposure to whole residue. The timer consisted of a round steel tank (61 cm in diameter) with a checkerboard opaque and a clear bottom, beneath which there were two photocells. Initiation of a solenoid sound source mounted on the side of the tank also caused a clock to start. When a fish moved in response to the sound, its shadow caused photocells to stop the clock. A sick or an irritated fish was expected to have a different reaction time than a normal fish.

The procedure was to place all the fish from a control tank or a 30% residue tank into 10 - 15 cm of water in the reaction timer. Fish were tested in batches because response was more likely and the readings less variable. The sound stimulus was activated manually when the activity meter indicated that the motion had stabilized. Twenty reactions to the sound were obtained for each batch. Each test group of fish was limited to two hours so they would not become conditioned to the stimulus. Temperature was recorded during each test and held constant to within ± 2 C throughout the test period.

Twenty separate reaction times for ten control and ten residue fish were obtained weekly over an 8 week period. These values were averaged and ranged from 0.049 seconds to 0.069 seconds, as shown in Table 4-19. The averages of the two sets of reactions were compared weekly by a two sided T-test at the 95% confidence level(4). None of the sets of two averages differed significantly from each other. The 30% residue concentration apparently had no influence on the reaction times of the fish to a sound stimulus.

C. Phytoplankton Growth Experiments

The effect of residue on phytoplankton is important because whatever affects their productivity affects all other levels of life. Growth studies were conducted to evaluate the effects of shading, toxicity, adsorption, and fertilization on 3 species of phytoplankton exposed to incinerator residue. The following organisms were used: (1)a pelagic diatom which needs cold water and a high concentration of inorganic nutrients for growth (2) a pelagic dinoflagellate which needs warm water, a high concentration of organic nutrients,and a low concentration of inorganic nutrients for growth and (3) a bottom diatom. These species represent the major phytoplankton populations which might be affected by incinerator residue.

TABLE 4-19

THE AVERAGE REACTION TIMES OF TREATED AND CONTROL *FUNDUS HETEROCLITUS* TO A SOUND STIMULUS OVER AN 8 WEEK PERIOD

				Average Reaction Time Seconds	
	Days	Temperature	Number of fish	Control Tank	30% Residue Tank
1	7	13C	20	0.067	.049
2	14	13C	20	.058	.061
3	21	15C	20	.054	.061
4	27	13C	20	.065	.056
5	35	13C	20	.062	.060
6	42	13-15C	20	.059	.059
7	49	13-15C	20	.073	.057
8	57	13-15C	20	.069	.068

The procedure was to grow the phytoplankton cultures in sterile 125 ml flasks with initial concentrations of 500 cells/ml. Pure cultures were obtained from B. Bolelyn at the Narragansett Marine Laboratory. Early Skeletonema cultures were grown at 10 C. Later cultures were grown at 15 C. Residue or residue components were added to Guillard's medium F nutrient solution to test for shading and toxicity affects. Residue extracts in sterile natural sea waters were used to test for toxicity and fertilizing effects.

Light was supplied by two 15 watt fluorescent lamps for early *Skeletonema* experiments, with illumination readings ranging from 120 to 150 foot candles. Light was supplied for *Olithodiscus* experiments by two 15 watt fluorescent lamps and one 20 watt fluorescent lamp with illumination readings ranging from 120 to 500 foot candles. For Nitzschia experiments, light was supplied by two 15 watt and two 20 watt fluorescent lamps with illumination readings ranging from 220 to 800 foot candles. As illumination levels of 400-800 foot candles are considered adequate, the illumination levels used for most experiments were low. Therefore, flask positions were rotated regularly to obtain as nearly equal illumination as possible for all flasks to cancel out the effect of low illumination differences.

Concentration of cells per milliliter was determined for each set of duplicate flasks by counting 9 Whipple disk areas twice in a Sedgwick-Rafter cell. The average of 9 Whipple disk areas times 166 equaled the number of cells per milliliter. Each experiment was carried out in duplicate, and, as two counts were made per flask, the final numbers represented the average of four counts.

Results of all phytoplankton growth experiments are summarized in Table 4-20. Best growth was obtained with the diatom S. costatum. Poorest growth occurred with the diatom N. paradoxa. Since control flasks did poorly, these experiments with the bottom diatom are only acceptable for rough comparisons with the other two species. In all the growth experiments conducted with whole residue, the number of cells was inversely proportional to the residue concentration. For all three species, the residue exerted a shading and/or toxic effect.

Phytoplankton were grown in residue extract to test for fertilizing or toxicity effects separate from the shading effect. Sargasso sea water which is very poor in nutrients and Wickford Harbor seawater were used in parallel experiments to be certain that the observed growth pattern was not solely due to the use of a foreign type of sea water. Only the diatom S. costatum grew in the Sargasso sea water and in this case the number of cells was directly proportional to the extract concentration. Although even the best growth was poorer than that observed in a nutrient medium, the extract apparently contributed some nutrients important for diatom growth. Results were variable with Wickford Harbor sea water. S. costatum grew well in control flasks and fairly well in lower extract concentrations but very poorly at

TABLE 4-20
PHYTOPLANKTON GROWTH (CELLS/ML) AFTER TEN DAYS

species	Whole Residue	Residue Extract Sargasso Sea Water	Residue Extract Wickford Sea Water	Washed Residue	Analogous Material
Skeletonema costatum					
concentration					
10%	t	72,000	1000		
5.6%	1100	65,000	90,000		5.6% Charcoal 40,000
3.2%	56,000	52,000	100,000		5.6% Glass 20,000
1.8%	310,000	72,000	80,000		
1.0%	360,000	58,000			
control	500,000	16,000	150,000		640,000
Olithodiscus luteus					
concentration					
10%	1000	t	0	2000	
5.6%	4000	t	t	1000	5.6% Charcoal t
3.2%	8000	t	1000	3000	5.6% Glass 2000
1.8%	17,000	t	3000	5000	
1.0%	40,000	t		14,000	
control	130,000	t	0	110,000	50,000
Nitzschia paradoxa					
concentration					
10%	0	0	t	t	
5.6%	t	0	1000	t	Charcoal 1000
3.2%	t	0	1000	1000	Glass 3000
1.8%	1000	0	1000	7000	
1.0%	5000	0	t	4000	
control	10,000	0	t	54,000	1000

t - less than 1000

high extract concentrations. The dinoflagellate O. luteus hardly grew at all and then only in the lower extract concentrations. This pattern was repeated by N. paradoxa. No clear interpretation of these results is possible. At lower concentrations there appeared to be a slight fertilizing effect for the two latter species, but an inhibitory affect on all 3 species at higher concentrations.

Growth experiments were carried out with washed residue and O. luteus and N. paradoxa to test for shading affect. For both species, growth was inversely proportional to concentration just as with whole residue. These results indicate that the residue exerts its inhibitory growth action by its light shading effect. To test this hypothesis and to determine if adsorption of cells on particulate matter inhibited growth significantly, each specie was grown with ground charcoal and ground glass. Both effects were observed with all three species (Table 4-20). Poorest growth occurred in charcoal with poor but better growth in glass.

At high residue concentrations, growth of phytoplankton appeared to be inhibited mainly by the shading effect with adsorption of cells onto particles exerting a substantial added lethal effect. Toxicity of the residue accounted for only a small fraction of the total growth inhibition. A slight fertilizing effect of the residue was detectable for the diatom S. costatum, but not the dinoflagellate in Sargasso sea water. A possible explanation is that diatoms need inorganic nutrients for best growth whereas dinoflagellates need some organic nutrients for their best growth. Inorganic, but no organic nutrients would normally be present in the residue.

Residue settling rates were measured by Taylor hydrometers and Jackson turbidimeters to determine whether residue would remain suspended in water for a sufficient period to inhibit phytoplankton growth. In a freshly made 10% whole residue concentration, 0.3% of the residue remained in suspension for a few minutes. After one hour, this value had dropped to 0.1%. After 24 hours, no detectable amount remained and the water appeared crystal clear to the eye. Therefore, it seems likely that concentrations of residue will not remain suspended in water long enough to inhibit phytoplankton growth significantly except in the local dumping area and then only for limited periods during active operations.

D. Hatching and Larval Experiments

Two brief experiments were carried out with fertilized winter flounder eggs. The first experiment, using residue extract, compared the development of control and treated eggs and larvae under a microscope. The second experiment, using whole residue and residue extract, compared the number of exposed fish that hatched to controls unexposed to residue or residue extract. Survival of lobster larvae in residue extract, washed residue, and whole residue was tested by modified bioassay procedures and the effect of residue on hatching and survival of zooplankton was observed.

1) Hatching experiments with winter flounder eggs.

Experiment 1

On February 28, 1967 fish from the outside control pen of the long term experiments spawned. Water temperature was 2 C. The spawn was divided equally between two plastic containers. One container held 0.5 l of sea water and the other held 0.5 l of residue extract. The containers were held at between 10.7 and 12.3 C.

Development of the fish in both containers was similar. On the eighth day in both containers embryos could be seen moving within the eggs and hearts could be seen beating. On the tenth day larval fish hatched in both containers. A rough estimate indicated the same numbers in both containers. On the eleventh day there appeared to be fewer animals in the sea water than in the extract. By the fourteenth day there were very few fish in either container and the experiment was terminated.

Experiment 2

On March 5, 1967 fish from the control pen again spawned. Water temperature was 3.5 C. Six containers for the eggs were set up. Two of the containers held 500 ml of sea water; two of the containers held 500 ml of 24 hour residue extract and two of the containers held 500 ml sea water and 5 gm of residue. All the containers were placed in a water bath at 11 C. An oxygen stone was added to each. To each container 5 gm of 2 day-old winter flounder eggs were added.

At 8 days fish hatched in all 6 containers. Counts of 10 ml samples yielded the following numbers of larvae:

	10 ml Sample			
	Container I		Container II	
	(1)	(2)	(1)	(2)
Control	0	5	0	0
1% Residue	7	13	11	16
24 Hour Extract	9	15	12	1

A 9 day count of 10 ml samples taken from the combined duplicate containers gave the following numbers of larval fish:

	10 ml Sample				
	(1)	(2)	(3)	(4)	(5)
Control	3	9	4	5	3
1% Ash	3	4	6	10	13
Extract	8	9	10	8	12

This more or less qualitative estimation indicated that the best hatch occurred in the 1% ash and ash extract containers. Thus, neither the ash nor the ash extract appeared to inhibit hatching or caused deformities in larval fish.

2) Larval experiments with lobster larvae (Homarus Americanus)

Three experiments were carried out on lobster larvae to test the effects of the residue on the young of these economically important species.

Experiment 1. Survival of first stage larvae in ash extract.

Approximately 100 first stage lobster larvae were placed into a control tank and a tank containing ash extract. The extract was made by filtering sea water constantly through ash and then returning the water to the experimental tank (Figure 4-10).

Numbers of larvae present were determined by sampling each tank 30 times with a 200 ml beaker and counting the larvae each time. A steady attrition occurred in both tanks, largely due to cannibalism. To determine whether the loss was greater in one tank than in another a sign test for paired observations was used(4).

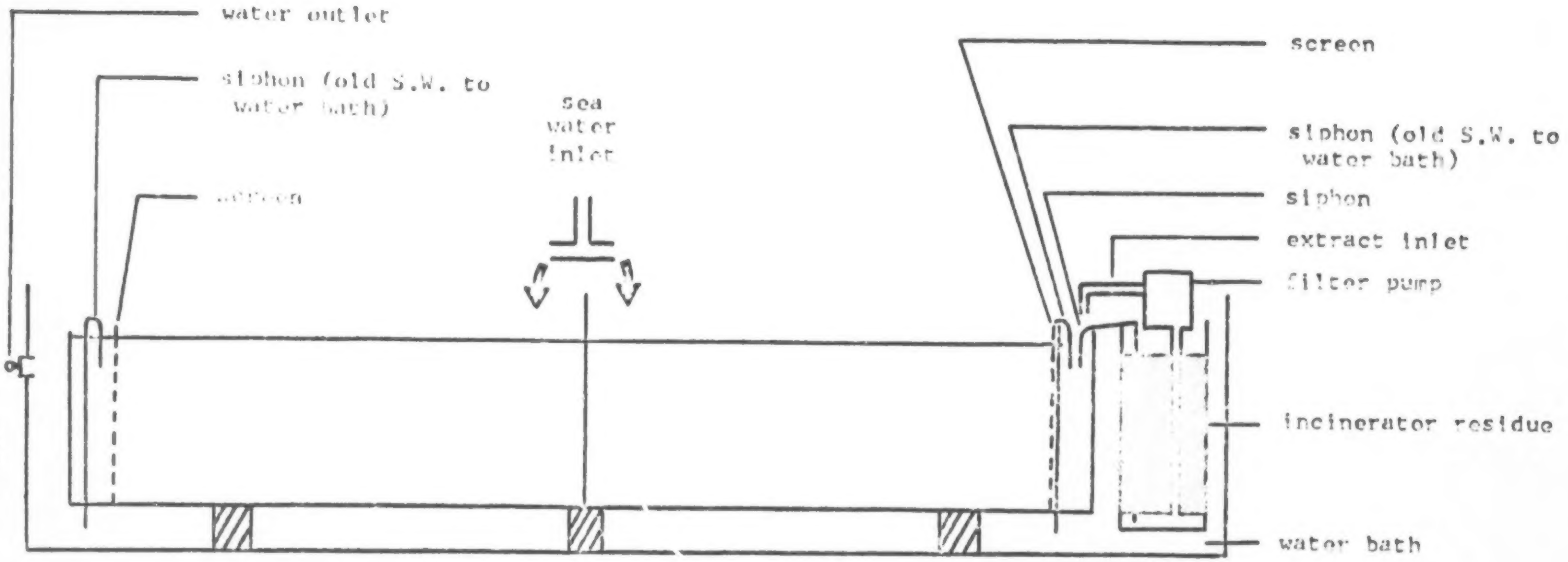
water outlet
siphon (old S.W. to water bath)
screen
sea water inlet
screen
siphon (old S.W. to water bath)
siphon
extract inlet
filter pump
incinerator residue
water bath

Figure 4-10. Diagram of 6 1/2 foot plexiglass tank arrangement used for lobster larvae survival in whole residue extract.

The actual test results are shown in Table 4-21. In almost every case, the number of larvae was greater in the extract than in the control. In addition, the sign test indicated a difference between the two tanks. However, more than 20% of the differences were equal to zero and beginning averages were greater for the extract than for the control. For these two reasons, it appears unlikely that a true difference in survival occurred between the two tanks. The main point is that the extract did not cause a mortality among the larvae.

A duplicate experiment was performed for three days and similar results were experienced.

Experiment 2. Survival of first and second stage larvae in 24 hour washed (extracted) ash.

A 1% concentration of ash which had been washed in sea water for 24 hours was made up in one tank. A similar tank containing only sea water was used as a control. Approximately equal numbers of larvae were added to each tank.

The same sampling procedure and sign test were used as an experiment 1. Results of the sign test, shown in Table 4-22, indicated

Table 4-21. **A sign test for Lobster larvae Survival in Ash Extract.**

1) $\alpha = 0.05$
2) $\bar{X}_a = \bar{X}_b$; when $n = 6$ days:

Number of Larvae per 200 ml

Control a	Extract b	Difference
1.36	1.63	- 0.27
0.70	1.70	- 1.00
0.23	0.60	- 0.37
0.50	0.50	---
1.13	1.36	- 0.23
1.26	1.26	---
0.60	0.90	- 0.30
0.46	0.76	- 0.30

3) $r = 0$
4) $r(\alpha, n) = r(0.05, 6) = 0$
5) $r = r(\alpha, n)$ Therefore, the averages differ, except (1) More than 20% = 0
(2) Begining averages were always greater for the extract than the control.

Table 4-22. A Sign Test for Lobster larvae Survival in 24 Hour Washed Ash.

1) α = 0.05
2) Xa - Xb and n = 8 days:

Average Number of Larvae per 200 ml

Control	Washed Ash	Difference
1.70	2.03	- 0.33
0.73	1.33	- 0.60
0.36	0.83	- 0.47
0.40	0.83	- 0.43
0.37	0.47	- 0.10
0.26	0.50	- 0.44
0.36	0.70	- 0.34
0.23	0.23	--- *

3) r = 0
4) r(α,n) = r(0.05,8) = 1
5) r is less than r(α,n), therefore, the averages differ, except beginning numbers were also greater in washed ash than in control tanks.

* Less than 20%.

Table 4-23 A Sign Test for Lobster Larvae Survival in Whole Ash.

1) α = 0.05
2) Xa - Xb and n = 12 days:

Average Number of Larvae per 200 ml

Control	Whole Ash	Difference
5.66	6.43	- 0.77
1.06	5.13	- 4.07
0.50	1.53	- 1.03
1.33	2.63	- 1.30
1.70	1.83	- 0.13
2.00	1.90	+ 0.10
1.76	1.43	+ 0.33
1.70	1.13	+ 0.57
0.36	0.40	+0.04
1.76	2.20	- 0.44 //
0.93	1.23	- 0.30 //
0.60	0.86	- 0.26 //

3) r = 4
4) r(α,n) = r(0.05,12) = 2
5) r is greater than r(α,n), therefore, the averages do not differ.

// 1 liter samples instead of 200 ml.

that the washed ash did not cause any mortality to the lobster larvae.

A duplicate experiment was performed for three days and similar results were experienced.

Experiment 3. Survival of first and second stage lobster larvae in whole ash.

A 1% concentration of whole ash which was allowed to settle 6 hours and then skimmed and a similar control tank containing sea water were used. Approximately equal numbers of first stage lobster larvae were added to each tank.

The same sampling procedure and sign test were used as in Experiment 1. Results of the sign test, shown in Table 4-23, indicated no differences in survival between the two tanks.

Experiment 4. Survival of fourth stage lobster larvae in whole ash.

A 5% concentration, a 10% concentration, and a control tank containing sea water were used. The ash was allowed to settle for 24 hours and the floating component was skimmed off. An oxygen stone was placed in each tank. Thirteen fourth stage lobster larvae were placed in each tank.

Results of the experiment, shown in Table 4-24 indicated a significant mortality in the 10% ash concentration. However, survival in the 5% ash concentration was comparable to survival in the control tank. The somewhat better survival in the 5% concentration was probably due to the fact that the ash debris provided cover, thus reducing canabalism among the larvae.

To summarize, ash extract concentration of 1%, washed ash concentration of 1%, and whole ash concentrations of 1% did not

Figure 4-24. Fourth Stage Lobster Larvae Survival in Whole Ash.

Survival	Control	5%	10%
	Whole Ash Concentration		
Day 1	77%	85%	6[illegible]%
Day 2	77%	85%	46%
Day 4	69%	85%	15%
Day 10	62%	77%	15%

Temperature range 14.2 - 1[illegible].0C

Table 4-25. **Survival and Hatching of __Tigrippus__ __japonicus__ in 24 hour Ash Extract.**

	Guillard's f/2			**24 Hour Ash Extract**		
	1	**2**	**3**	**1**	**2**	**3**
Day 0	**10-2eggers**	**10-2eggers**	**10-2eggers**	**10-2eggers**	**10-2eggers**	**10-2eggers**
Day 1 Survival	**10-2**	**10-2**	**10-2**	**10-2**	**9-1**	**10-2**
Day 2 Survival	**10-2**	**10-2**	**10-2**	**10-2**	**9-1**	**10-2**
Day 4 Survival	**10-2**	**10-0**	**10-2**	**10-2**	**9-1**	**10-2**
Day 7 Survival	**10-2**	**10-2**	**10-2**	**10-1**	**9-0**	**10-1**
Day 14 Survival	**7-1**	**8-1**	**10-2**	**9-2***	**9-2***	**10-2***

*** 25 plus young had hatched.**

	Guillard's f/2	24 Hour Ash Extract
Total Died:	**5**	**2**
Total lost Eggs:	**5**	**4**
Hatching:	**No**	**Yes**

appear to harm first and fourth stage lobster larvae. Fourth stage lobster larvae did not survive well in whole ash concentrations of 10%, but were apparently not harmed by a concentration of 5%. Rather in this lower concentration the larvae were observed to take advantage of all the hiding places created by residue rubble and consequently cannibalism was reduced.

3) The effects of residue extract on the zooplankter Trigiopus japonicus

A culture of Trigippus japonicus with Pseudomonas #5 (a member of the zooplankton which can be readily cultured and the phytoplankton upon which it feeds) was obtained from the Narragansett Marine Laboratory. A survival and hatching experiment was set up with this animal and allowed to run for 14 days at 15 C.

Three petri dishes containing 15 ml of Guillard's medium f/2 and three petri dishes containing 24 hour whole ash extract were set up. Into each petri dish 10 animals were introduced with 2 of the 10 bearing egg sacs. Pseudomonas culture was also placed in each dish for the zooplankton to feed upon. Results are summarized in Table 4-25.

The extract caused less mortality than the culture medium. Also hatching occurred in the extract but not in the medium. Therefore it seems safe to say that the extract had no ill effects on the Tigrippus. However, it should be pointed out that Tigrippus cannot be compared with natural zooplankton. Natural zooplankton are very difficult to culture and are much more sensitive to environmental change than Tigrippus.

IV. TOXICITY OF SUSPENDED MINERAL SOLIDS TO ESTUARINE FISH

Bruce A. Rogers

A. Introduction

Two hypotheses have been proposed to account for deaths among fish exposed to incinerator residue in test aquaria. The first is that a toxic soluble material leaches out of the residue into the sea water. This hypothesis was tested by exposing test animals to sea water extracts of the soluble fractions of the residue and to leached colloids containing no soluble material. The second hypothesis is that fine particles of residue suspended in water cause mechanical damage to fishes' delicate respiratory structures. The analogy between the physiological problems of the survival of experimental fish in suspensions of fine particulate incinerator residue and the situation encountered by fish in silt-laden streams is clear but no quantitative information was available on lethal levels of suspended mineral solids for marine fish.

Investigations of the effects of suspended mineral solids on freshwater fishes have been made by Griffin(11) who noted that trout and salmon survived three to four weeks in silt suspensions up to 6900 ppm. Wallin(12) determined the tolerances of 16 species of freshwater fish to suspensions of montmorillonite clay and erosion silt. He noted that test animals of all species survived for up to one week in suspensions of 100,000 ppm concentration. Concentrations of from 175,000 to 225,000 ppm proved fatal within a few hours. Herbert and Merkens(13), using a series of suspended mineral solids found in certain industrial effluents, tested the effects of chronic exposure of rainbow trout, Salmo gairdnerii, to suspensions of 30 to 1000 ppm. They noted high mortality among trout exposed for up to 180 days of suspensions of kaolinite clay and Diatomaceous earth and Diatomaceous earth suspensions were found to be somewhat more toxic. The introduction by Herbert and Merkens of apparatus to maintain solid material in suspension was an improvement over earlier studies which relied on periodic hand mixing to maintain suspensions.

The present study is an investigation of suspensions of incinerator residue and other particulate mineral materials on certain marine fish species common to the inshore waters of Rhode Island and a study of the mechanisms by which particle suspensions affect fish.

B. Materials and Methods

After preliminary experiments to determine the approximate concentrations at which fractional mortality or survival might occur, a series of test concentrations were chosen such that all of the concentration range between zero mortality and 100 percent mortality was represented. Concentrations used in a given test series were evenly spaced when plotted on a logarithmic scale.

All of the particulate materials used were available as dry powders. Suspensions of any concentration were prepared by weighing out the appropriate amount of dry powder on a triple beam balance and adding this material to a measured amount of sea water in the test aquarium.

Experimental Apparatus:

All experimental bioassays were performed in specially constructed test aquaria designed to keep mineral particles in suspension. Such apparatus had to provide sufficient agitation to maintain a homogeneous suspension even at high particle concentrations and still protect the experimental animals from excessive turbulence. The test aquaria used in this study represented a compromise between these two requirements.

Each test vessel was constructed from an 8 liter Pyrex percolator jar which was conical(Figure 4-11). .In use, each was filled with 6 liters of suspension. A cylindrical Lucite standpipe 5 cm. in diameter and open at each end stood in each cone extending from the apex or bottom of the cone to the water surface. A series of perforations near the bottom and near the water surface permitted free water flow. Annular screens made of 1/4 inch mesh galvanized hardware cloth coated with epoxy paint were placed in each test cone just under the water surface and 10-15 cm from the bottom of the cone to keep the test animals in the

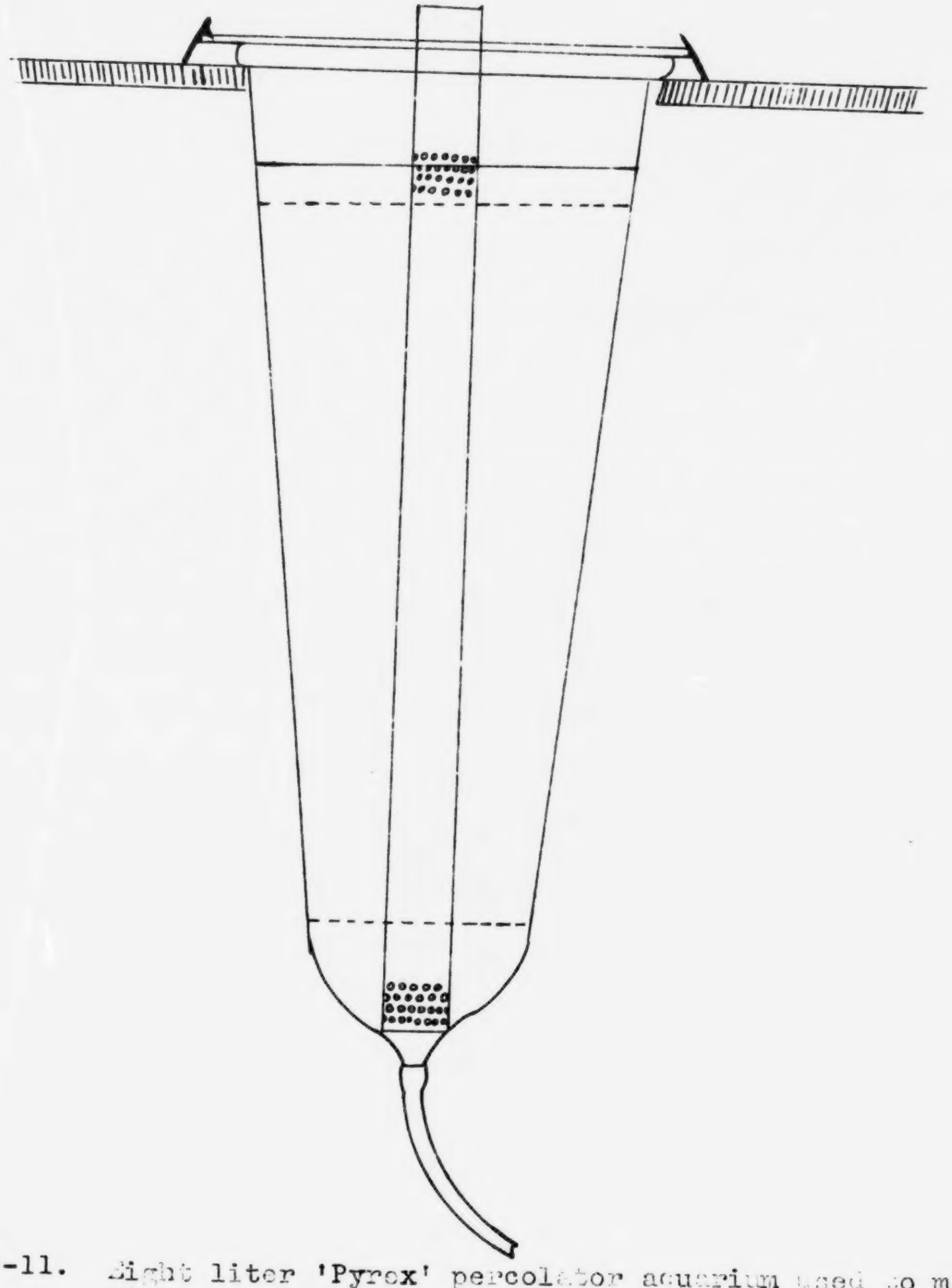

Figure 4-11. Eight liter 'Pyrex' percolator aquarium used to maintain mineral particles in suspension during bioassay experiments

experimental suspension and to prevent dead or immobilized animals from clogging the intake holes at the bottom of the standpipe. Air bubbling through the bottom of the cone and up through the standpipe created a current which lifted particles which had settled to the bottom of the cone back to the surface. The volume of air released was maintained at a level sufficient to prevent the accumulation of particles at the bottom of the cone and yet not so high as to suck the test animals against the lower screen.

Six such conical test vessels were made, however, the number which could be operated at one time was limited by the output of the small air compressor used. This limitation became critical when a series of highly concentrated suspensions had to be maintained, each requiring a relatively large air volume. As a result it was not always possible to run a wide range of concentrations simultaneously. The test aquaria were kept partially immersed in a large wooden waterbath which prevented wide fluctuations in temperature during the assays, and permitted the assessment of the effect of temperature on suspended particle toxicity. Water temperature in the bath was controlled by circulating cooled water through copper coils in the bath or by an electrical heating coil coupled to a thermoregulator.

Preparation of Experimental Suspensions

Finely divided mineral materials were either purchased as dry powders or dried in air under a heat lamp before being weighed out for use in bioassay experiments. Naturally occurring sediments were sieved to remove most sand-sized particles using a piece of 0.125 mm mesh bolting. Particles larger than this were difficult to maintain in suspension and in nature may be expected to be found in suspension only in the most turbulent conditions. While the upper size limits of particles used to prepare test suspensions could be determined by sieving, the lower end of the size distribution was more difficult to control. Sedimentation methods could have been used, but were abandoned because they required wetting and redrying the sediment before being weighed out. Instead, a series of mineral materials of differing though often overlapping size distributions were used. The size distributions of particle types used in the majority of the bioassays are shown in Figure 4-12. Size distributions were determined using a Standard Tyler Series of sieves for particles larger than 0.062 mm. The fraction of particles smaller than 0.062 mm was sized using a Bouyouco's hydrometer. For both sieve and hydrometer analyses the procedures outlined in Lambe (14) were followed.

Four different mineral powders were used to prepare the various suspensions used in this study.

Kingston Silt

So-called "Kingston Silt" is a naturally occurring glacial rock flour which was collected from an exposed outcropping in an excavation near Kingston, Rhode Island. This abundant material is of uniform size distribution and contains only a small amount of sand which had to be removed by sieving before use. For these reasons that it was used in more experiments than the other materials discussed below. Before use the "Kingston Silt" was dried and passed through a 0.125 mm. sieve.

Diatomaceous Earth

Diatomaceous Earth (Dicalite 4200_R Great Lakes Carbon Corp.) used commercially in swimming pool filters was used in a number of preliminary experiments and in experiments to assess the effect of particle shape on the toxicity of suspensions. This material was sieved to remove particles larger than 0.125 mm. and air dried before use. Diatomaceous earth is composed of fragments of fossil diatom frustules. Individual particles are highly angular and adhere to one another in suspension forming clumps of variable size. Although individual particles could readily

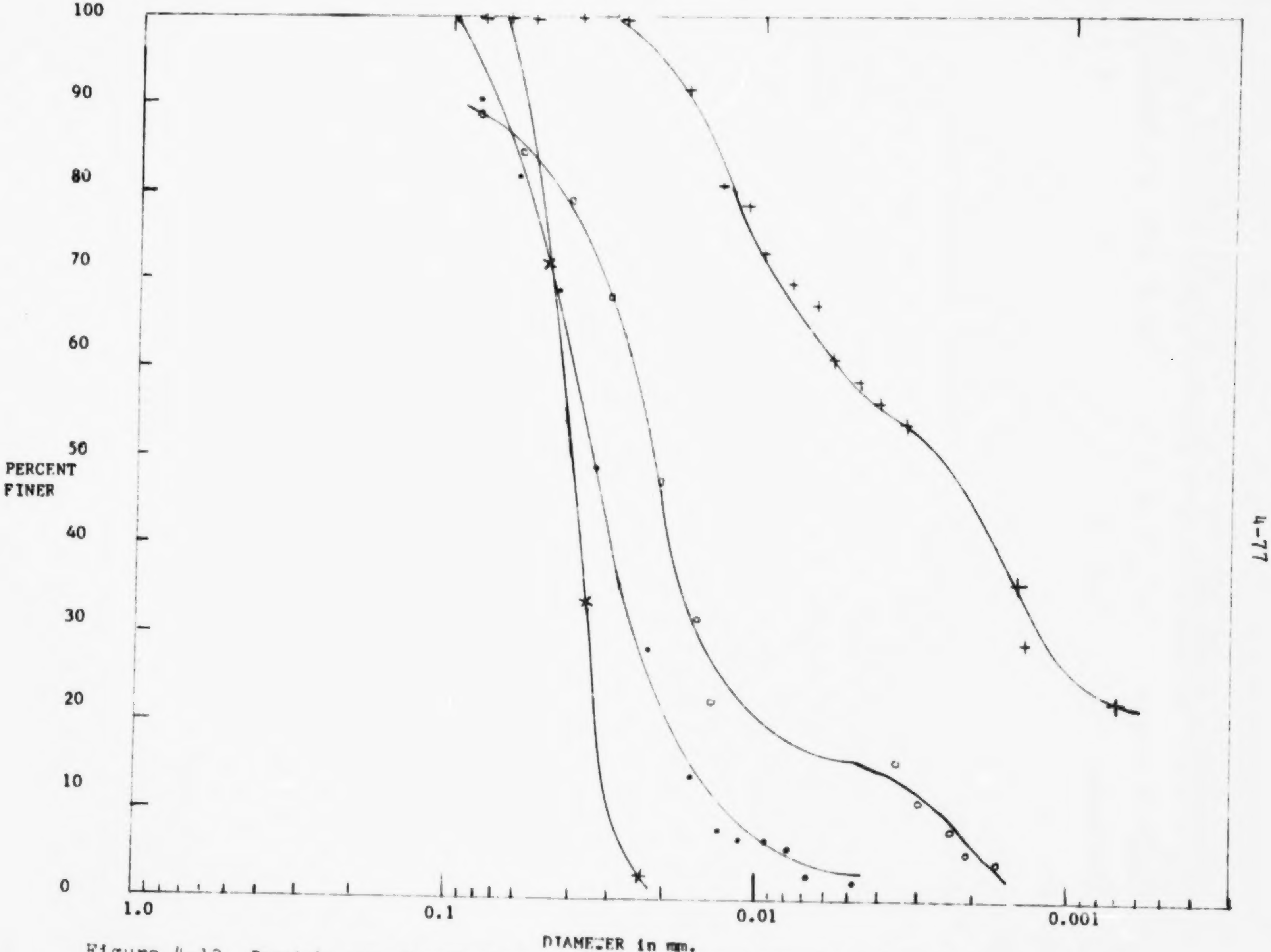

Figure 4-12. Particle size distributions of four experimental materials: (X) incinerator residue, (•) Kingston silt, (∘) diatomaceous earth, (+) Kaolin clay

pass through the retaining screens, in the test aquaria these screens often became clogged, restricting the circulation of the suspension. Such clogging prevented the maintenance of suspensions of constant known concentration. For this reason the use of diatomaceous earth was abandoned in later experiments.

Kaolinite Clay

Kaolin clay was used in several experimental series. This material (Kaolin J.T. Baker Co.) was purchased from a scientific supply house and used as supplied. A fine powder, kaolin resisted wetting and had to be made into a slurry with water from the appropriate test container using an electric stirrer before being added to the experimental aquaria. The particle size distribution of this material given in Figure 4-12 was determined using a hydrometer in distilled water with no deflocculateing agent. In ion-rich media such as sea water, Kaolin flocculates readily. These aggregates of individual clay particles sediment more rapidly than individual particles. Electron microscope studies of kaolinite

reveal plate-like particles approximately 1.5 microns on the long axis and 0.08 microns thick. Marine fishes in experimental suspensions in sea water encountered aggregates of clay particles larger than unitary clay particles.

Fine Fraction Incinerator Residue

Samples of incinerator residue were taken from Boston's South Bay Incinerator. Although inherently heterogeneous in nature, these samples were assumed to be representative. Raw residue was passed through a one inch wire screen before being shipped to Rhode Island for use in toxicity bioassays. Several residue samples as received from Boston were pooled and sieve analyses were run on 8 splits from this pooled sample (Figure 4-13). Only material which passed through the 0.062 mm sieve was used in experimental suspensions. The

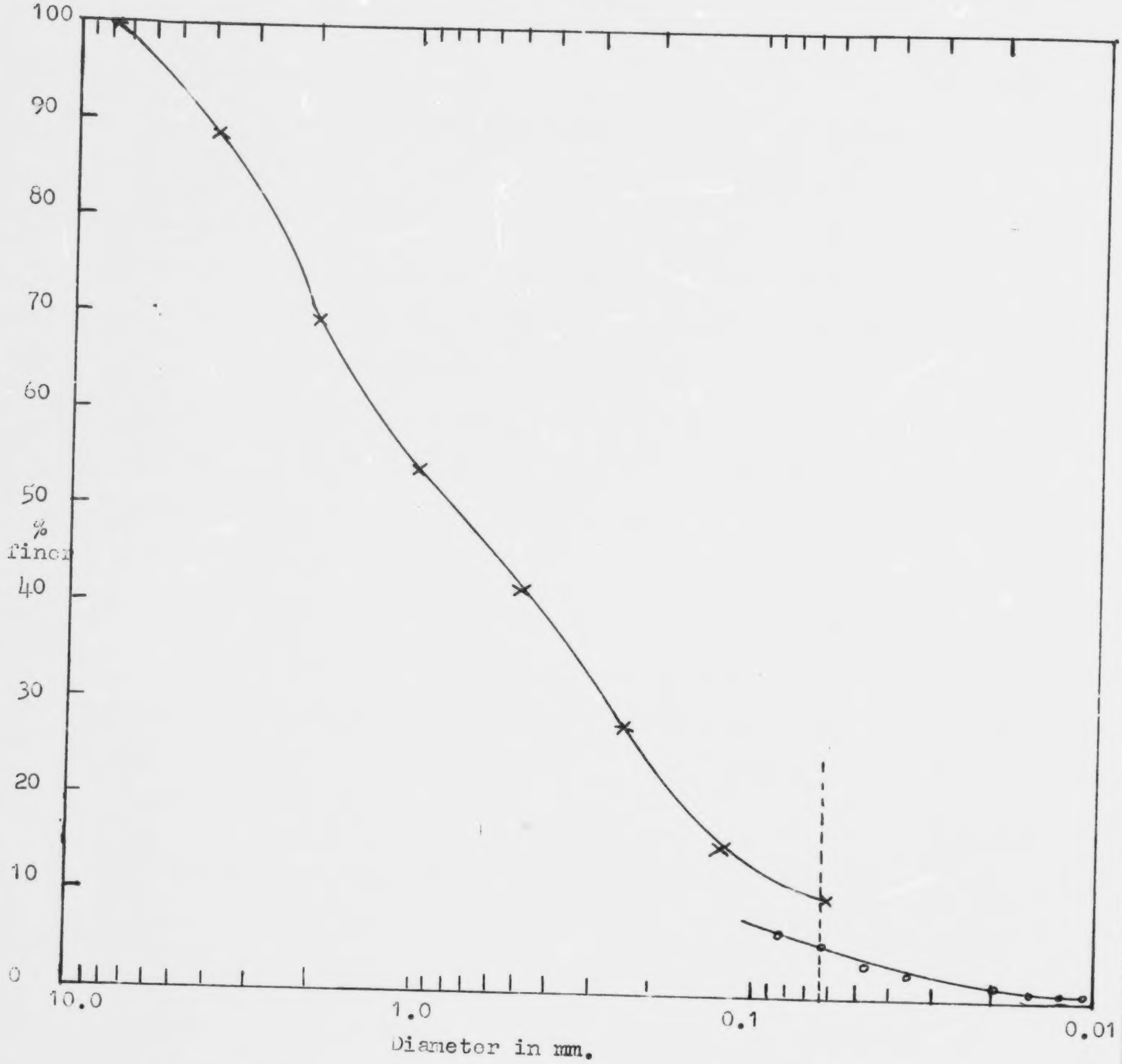

Figure 4-13. The grain size distribution of incinerator residue in general toxicity bioassays as determined -- sieving (x) and by Bouyoucos hydrometer(o). Dotted line delimits largest particles used in suspended particle bioassays.

portion used represents approximately 5-6% by weight of the material as supplied from Boston and represents an even smaller fraction of the residue as it is discharged from the incinerator.

Since much sieving was necessary to obtain sufficient quantities of fine material for use, residue suspensions were reused in several assays after sedimentation, washing in fresh water,and redrying. Dry fine fraction residue resisted wetting and had to be added to the experimental aquaria as a slurry prepared from test water using an electric mixer. It was found that if the fine residue fraction was heated in an oven prior to addition to the test aquaria, it wetted readily and virtually none of the material floated.

Other Materials Used

Several other particulate materials were used in a limited number of experiments designed to demonstrate the effect of particle shape on the toxicity of experimental suspensions.

Glass Shards

Fragments of window glass were pulverized to a fine powder in a ball mill. Particles larger than 0.062 mm were removed by sieving.

Charcoal

Finely powdered bone charcoal was used in one experiment. This material (Baker Activated Bone Charcoal) was purchased from a scientific supply house and used as supplied. The manufacturer claims that an upper size limit of 325 mesh or 0.044 mm for this material. The particle size distribution was not determined.

Glass Spheres

Glass spheres used commercially in the preparation of reflective surfaces were purchased from the Microbeads Division of the Cataphote Corp. of Jackson, Miss. Particles larger than 0.062 mm were removed by sieving. The manufacturer claimed that less than 10% of the particles were imperfect spheres. Microscopic examination of samples of this material revealed no basis for refuting this claim.

Experimental Animals

The following fish species served as test animals in these studies: the cunner, Tautogolabrus adspersus (Walbaum) 1792 (Labridae), the common mummichog, Fundulus heteroclitus (Linnaeus) 1776 (Cyprinodontidae), the sheeps head minnow, Cyprinodon variegatus (Lacepede) 1803 (Cyprinodontidae) and the four-spined stickle-back Apeltes quadracus (Mitchill) 1815 (Gasterosteidae). These species could be obtained by seining or trapping in all but the winter months and all survived well in captivity. All proved capable of withstanding the handling that was involved in the experimental procedure. All of the species that were used are common to the inshore waters of Rhode Island. Fundulus heteroclitus was collected using a small seine from a muddy cove in a salt marsh in Wickford Harbor. Apeltes quadracus was trapped in the early spring off the dock in Wickford Harbor or seined later in the summer over submerged Zostera beds in the Pettaquamscutt River near Middlebridge, in Narragansett, R.I. Cyprinodon variegatus was often taken with F. heteroclitus in the Wickford marsh. Some C. variegatus were collected near the mouth of a fresh water brook in Green Hill Pond in Green Hill, Rhode Island. F. heteroclitus, A. quadracus and C. variegatus are omnivores and are regular inhabitants of brackish water areas. The cunner, Tautagolabrus adspersus, was trapped off a dock in Wickford from April through October. Found infrequently in brackish waters, this species is a ubiquitous inhabitant of open rocky shore lines(16).

After capture the animals were kept in wire cages in a holding tank equipped with running sea water where they remained until they were used in toxicity assays. Animals which were held for several weeks were fed clam meats.

In an attempt to standardize toxicity bioassay procedures, some authors have prescribed fixed acclimation periods during which experimental animals are to become acclimatized to laboratory conditions. Due to the limited number and specialized nature of the test aquaria, it was impossible to acclimate animals to the conditions to be encountered during the bioassay itself. Animals were kept in wire cages at least 3 days after capture before being used in toxicity experiments. In several experiments using Tautogolabrus adspersus the fish which were used had been caught only an hour earlier. There was no apparent evidence that fish that had been in captivity for several weeks were any hardier than freshly caught animals. Animals kept in glass aquaria especially during the fall and winter months contracted a series of diseases that seriously affected their ability to survive in experimental suspensions. Freshly caught animals seldom showed signs of disease.

Only adult Apeltes quadracus, Cypriodon variegatus and Fundulus heteroclitus were used. Tautogolabrus adspersus used were young adults 6 to 10 cm. in total length. Although fish were collected throughout the spawning seasons of the species used, no emaciated post-spawned individuals were used.

Experimental Procedures

Once the nature of the particles and the concentrations to be used have been decided upon, appropriate amounts of dried particulate material were weighed out and set aside for use in the experiment. The test aquaria were then filled with a measured amount of sea water from the building's sea water system. No prior filtration of the sea water used in these experiments was attempted. In all cases the sea water used had a turbidity value below that which could be measured using the Jackson turbidimeter (less than 25 JTU). A concurrent control in an identical test aquarium using the same sea water as was used to prepare the experimental suspensions was run with each experiment. Mortality among controls rarely occurred and when it did it could generally be traced to disease among the fish in the holding tank. No data have been reported for experiments in which mortality occurred among animals in the concurrent control. After being examined for signs of disease or injury, experimental animals were removed from their holding cage and ten (10) individuals were placed in each experimental aquarium and in the control. The upper wire retaining ring was then put in place just below the water level in each aquarium. The air compressor was turned on and the air flow through each aquarium adjusted. Compressed air bubbling up the standpipe provided both agitation for the suspension and a source of dissolved oxygen for the experimental animals. Animals were left in the aquaria at least thirty minutes before any particulate materials were added. The experiment was begun at the time at which the mineral powder was added to the experimental aquaria, either as a dry wettable powder or as a previously prepared slurry. The air supply to each aquarium was then readjusted to a level well above the level sufficient to keep any particles from sedimenting at the bottom of the aquaria. Initial temperature readings were made in each aquarium and in the water bath. Water in test aquaria rapidly adjusted to the temperature being maintained in the water bath. Experimental temperatures used were within 5° C. of the temperature in the holding tank. The salinity of water drawn from the bottom of Wickford Harbor ranged from 25 to 29 o/00. Dissolved oxygen levels were not monitored for each experiment due to the difficulty of getting the electrode into the suspension, agitating it and removing it without releasing the test animals. Observations on aquaria without animals in them revealed oxygen values at air saturation levels in controls and at values slight below this for aquaria containing test suspensions.

Experiments generally were terminated after 24 hours. Experiments of 48 and 96 hours or longer were dismantled, examined and reassembled every 24 hours. At the end of the experiment the compressed air supply was shut off to one aquarium at a time. The entire aquarium unit was then removed from the water bath, the upper screen removed and the suspension poured through a screen to remove the experimental animals. The temperature of the water in each aquarium was recorded and the number of survivors noted. The condition of the animals not killed was noted. In some cases the survivors were removed to clear water aquaria for observations for subsequent mortality. Length frequencies were recorded for both surviving and dead animals at the end of each experiment. After each experiment all parts of the experimental and control aquaria were scrubbed clean with tap water and dried. Used suspensions were usually discarded.

C. Presentation of Data

For biological data in which a quantal response is expected, an S-shaped curve is generally encountered when the strength of the stimulus is plotted against the percent of test animals responding. Just as the sigmoid response curve itself is a function of the inherent variability in the response of test animals to a given stimulus, inherent variability in addition to changes in experimental conditions, however slight, prevents the exact repetition of an animal's response to a given stimulus in successive trials. Data given in the section that follows represent the pooled results of repeated trials performed under similar but never identical conditions. Variability in response and in conditions between trials prevents the results of a series of bioassays from closely approaching the expected sigmoid form. Fitting a sigmoid curve to heterogeneous data is difficult and inprecise. Two scale transformations have been applied to bring the data into a more easily interpreted linear form. Concentration, plotted on the abcissa, is expressed as the logarithm of the concentration in grams per liter. Percent responding or killed is plotted on a probit scale(17). In many cases considerable heterogeneity persists inspite of these scale transformations. Straight lines have been fitted to data points by eye where possible.

D. Results and Discussion

The Relative Toxicity of Incinerator Residue Suspensions

Suspensions of incinerator residue appear to be more toxic to A. quadracus and to T. adspersus than suspensions of Kingston silt of the same concentrations. Fig. 4-14 shows the results of bioassays using A. quadracus on both Kingston silt and fine incinerator residue. In residue assays there is only a 3 gm./l. difference between concentrations that produce no mortality and concentrations that produce 100% mortality. The steepness of the residue response curve is in contrast with that of Kingston silt. Fig. 4-15 shows bioassay results of incinerator residue, Kingston silt and Kaolin clay on T. adspersus. Although no response curve has been plotted for kaolin suspensions, they clearly exhibit a lower level of toxicity than those of either residue or Kingston Silt. The response of T. adspersus to increasing concentrations of residue is more erratic and less abrupt than that of A. quadracus. The apparent LD_{50} concentration for T. adspersus in residue suspensions is nearly twice that of A. quadracus. Fig. 4-16 reveals another case, in this instance involving F. heteroclitus, in which suspensions of different materials elicit mortality at markedly different concentrations. The bioassay experiments used to obtain the data used in each of the above comparisons were run within a narrow temperature range.

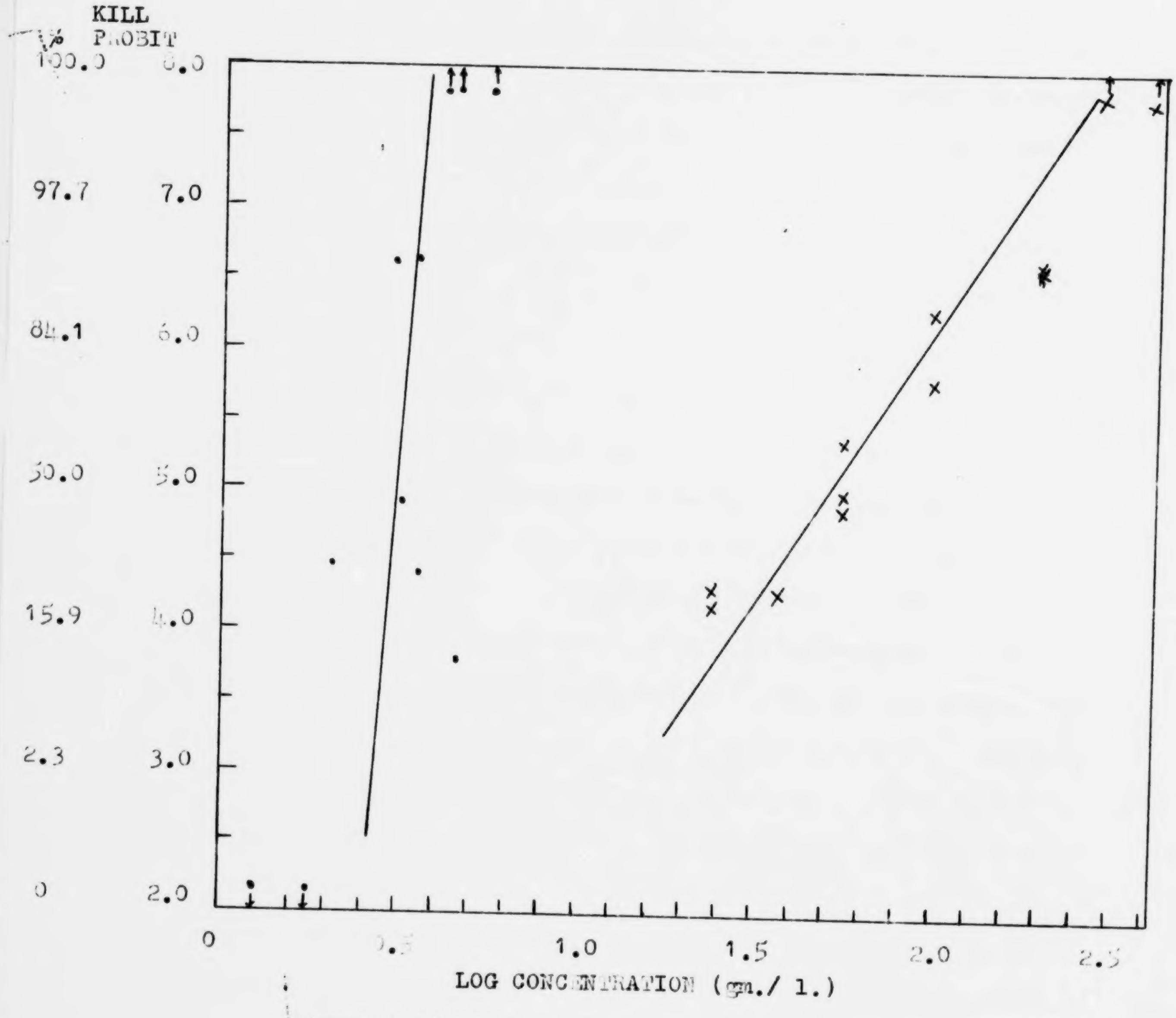

Figure 4-14. A comparison of mortality among sticklebacks, A. quadracus in suspensions of (.) incinerator residue, and (X) Kingston silt at 10 - 12°C.

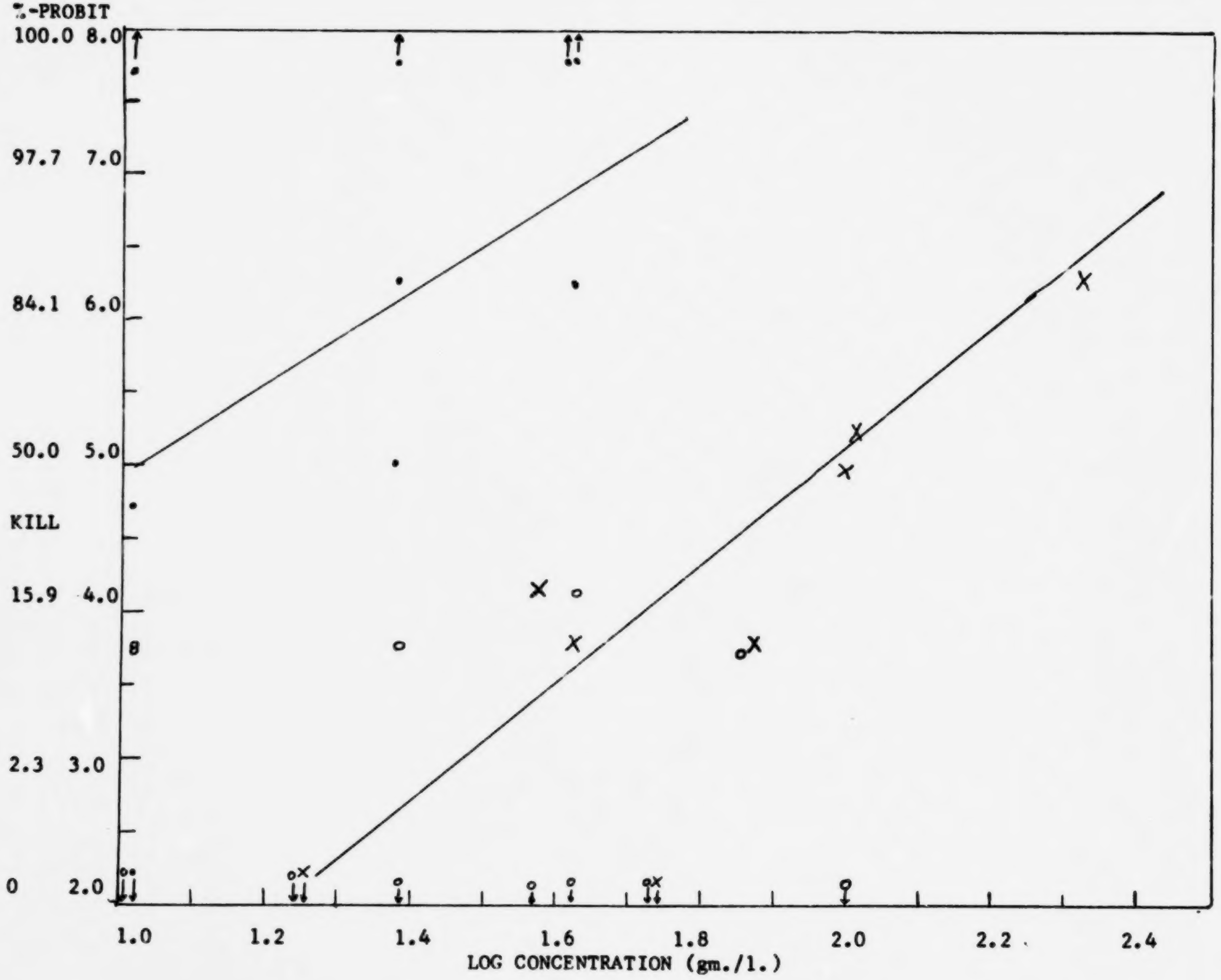

Figure 4-15. Acomparison of mortality among cunner, T.adspersus after 24 hours exposure to suspensions of (•) incinerator residue, (X) Kingston Silt and (o) kaolin clay at 15_{o_C}

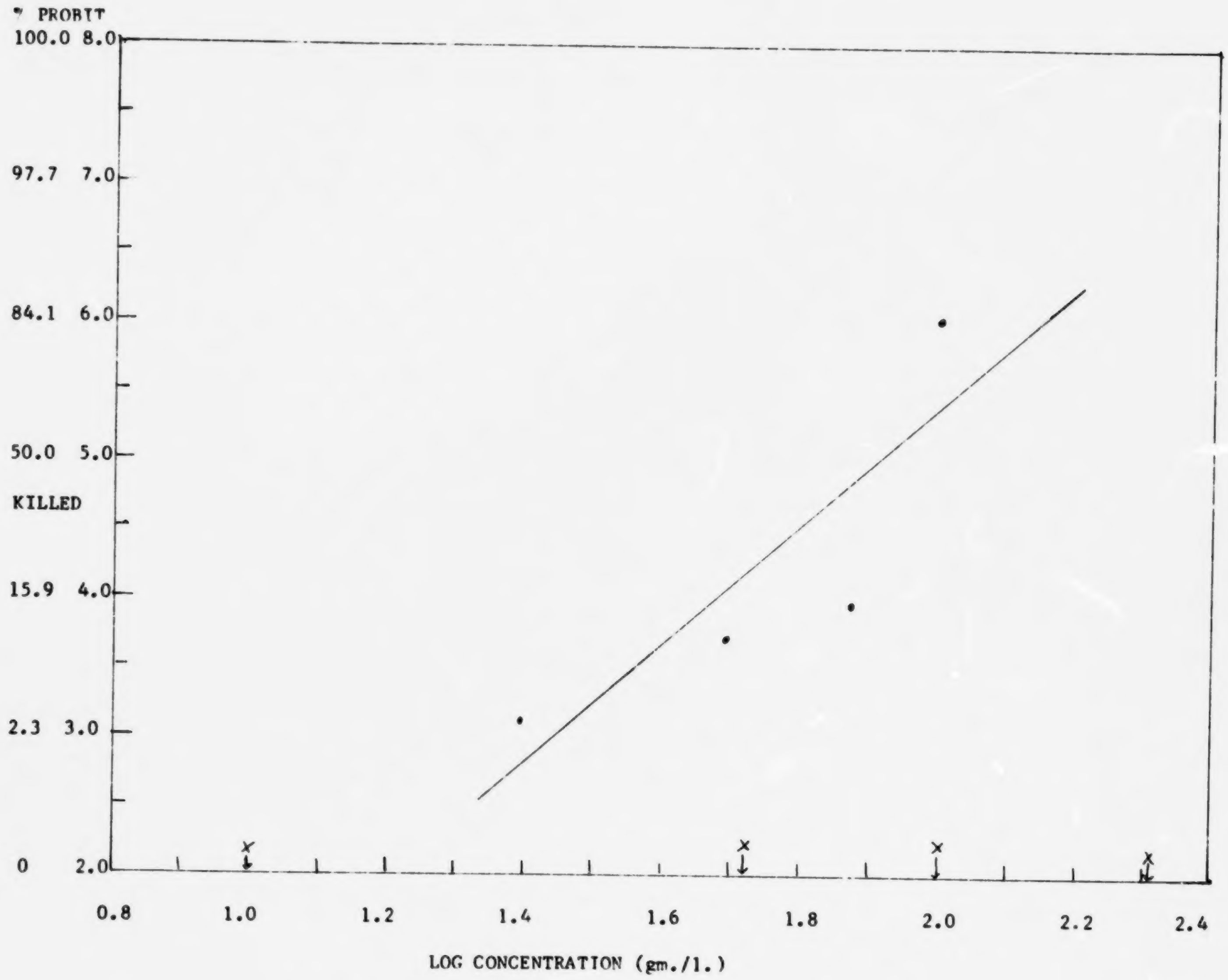

Figure 4-16 A comparison of mortality among mummichogs, F. heteroclitus after 24 hours in suspensions of (•) diatomaceous earth, (X) Kingston silt at 12°C.

The Effect of Temperature on the Toxicity of Experimental Suspensions

Changes in temperature had a pronounced effect on the toxicity of experimental suspensions. Levels of mortality over a given concentration range increased with increasing temperature. Figure 4-17 illustrates the increased vulnerability of A. quadracus to Kingston silt suspensions with increasing temperature. No explanation is offered for the lack of parallelism between the 9.0-9.5°C. line and the 10-12°C. and 15-16°C. lines. It is clear that the increase in vulnerability does not increase linearly with temperature. An example of a change in apparent toxicity with a change in temperature can also be seen in Figure 4-18 which represent the results of experiments using T. adspersus in suspensions of Kingston silt. The toxicity of Kingston silt suspensions to C. variegatus was also affected by temperature. (Figure 4-19).

The lack of sufficient data prevents the formulation of a generally applicable function relating mortality levels with temperature for a given species and material.

The phenomenon of increasing susceptibility to the action of toxic agents with increasing temperature is common, and is based on the temperature dependence of the metabolic rate of fishes. It is reasonable to expect that if the effect of temperature on the toxicity of suspensions of one material can be demonstrated, other materials in suspension will exhibit a similar increase in apparent toxicity with an increase in temperature. Although not demonstrated, it is felt that the apparent toxicity of incinerator residue would change with temperature.

The Effect of Exposure Time on the Toxicity of Experimental Suspensions

Data presented in Figure 4-20 illustrate the effect of exposure time on mortality levels among T. adspersus in Kingston silt suspensions at 15°C. The apparent toxicity of the suspension increased as the exposure time increased from 12 to 48 hours. A linear relation results when exposure time is plotted

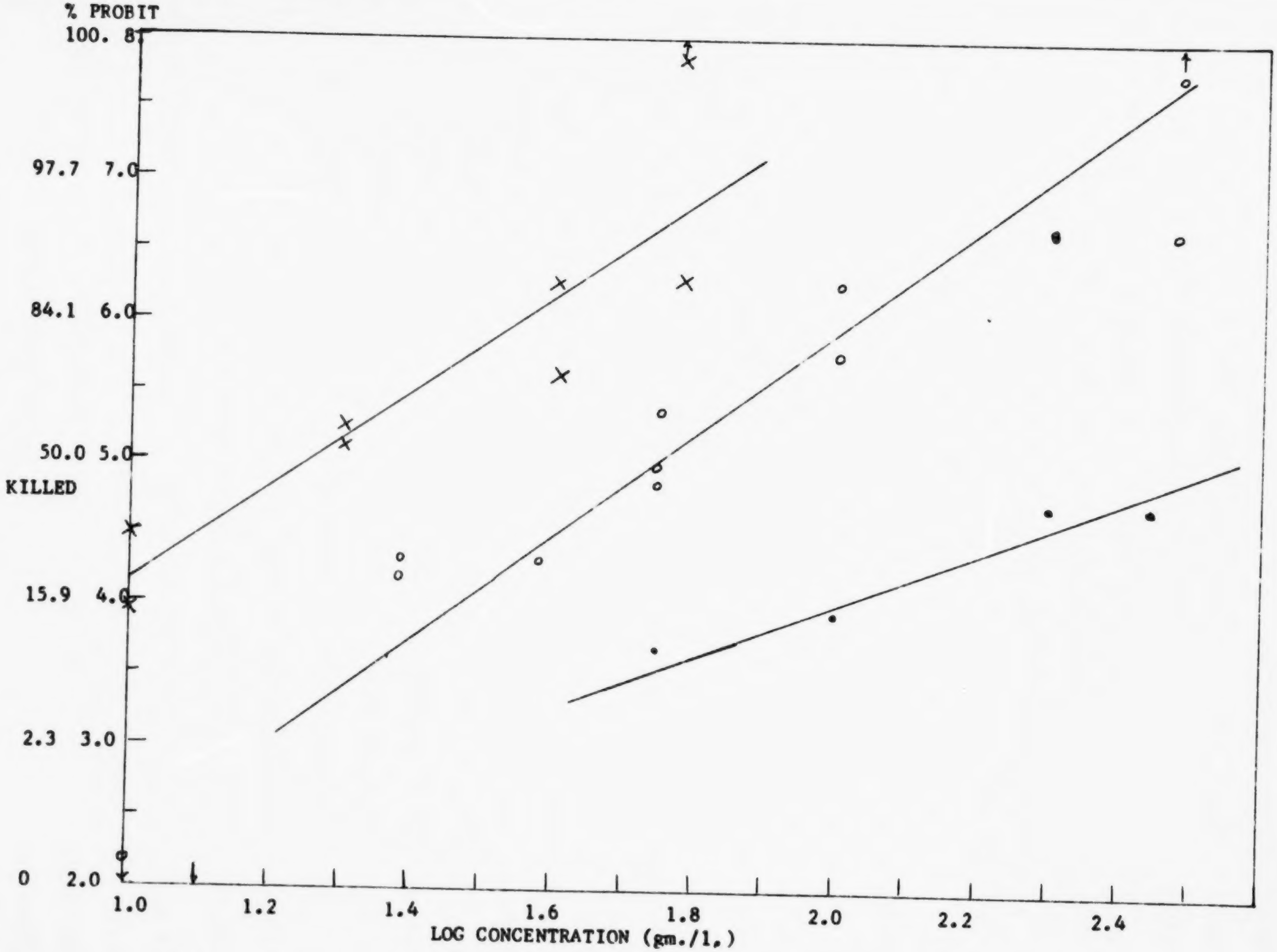

Figure 4-17 **The effect of temperature on the toxicity of suspensions of Kingston silt to sticklebacks, A.quadracus after 24 hours exposure at: (X) 15-16° C (o) 10-12° C. and (•) 9.0-9.5° C.**

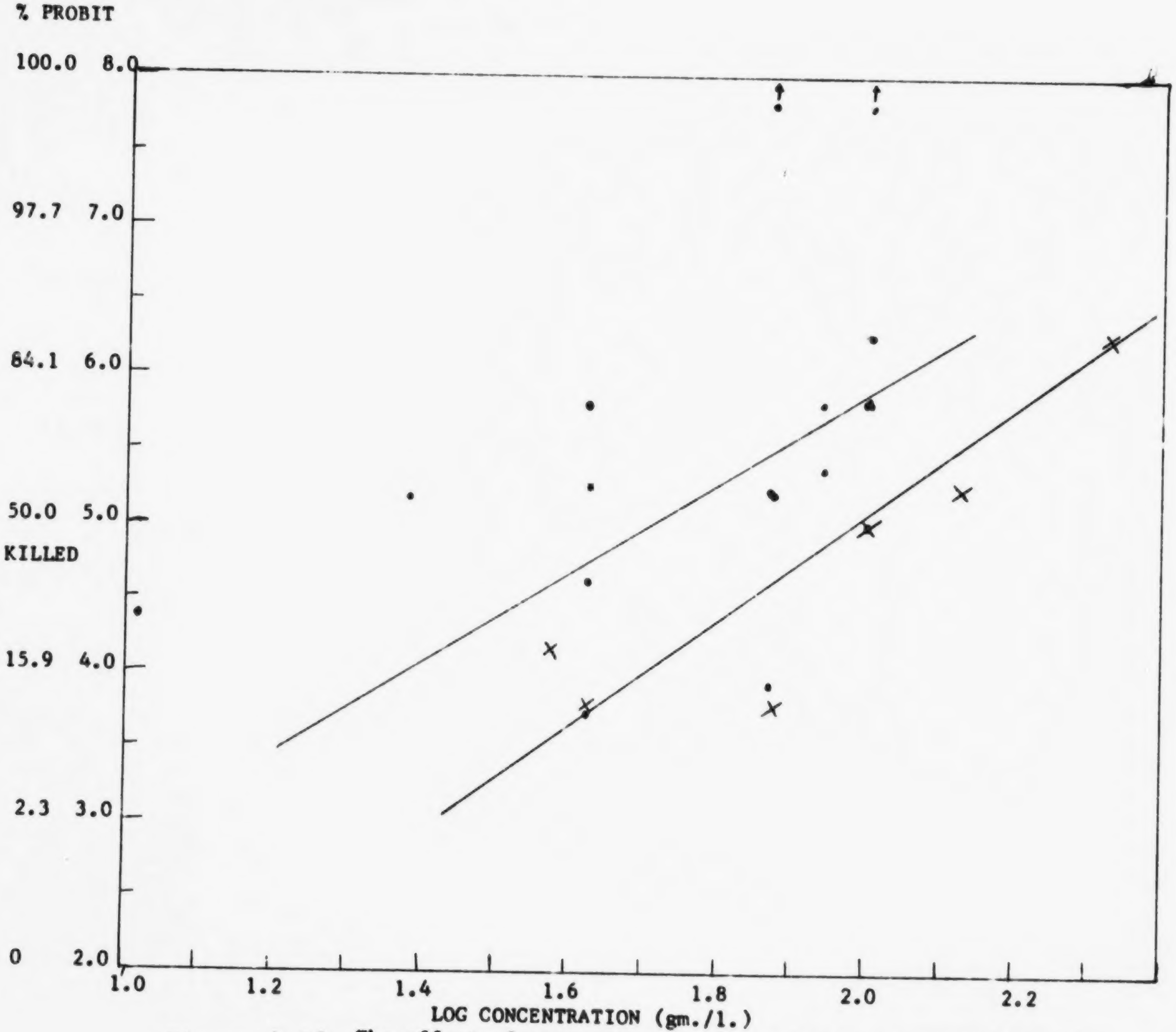

Figure 4-18. The effect of temperature on the toxicity of suspensions of Kingston silt to cunner, T. adspersus after 24 hours exposure at: (•) 20-25° C., (X) 15° C.

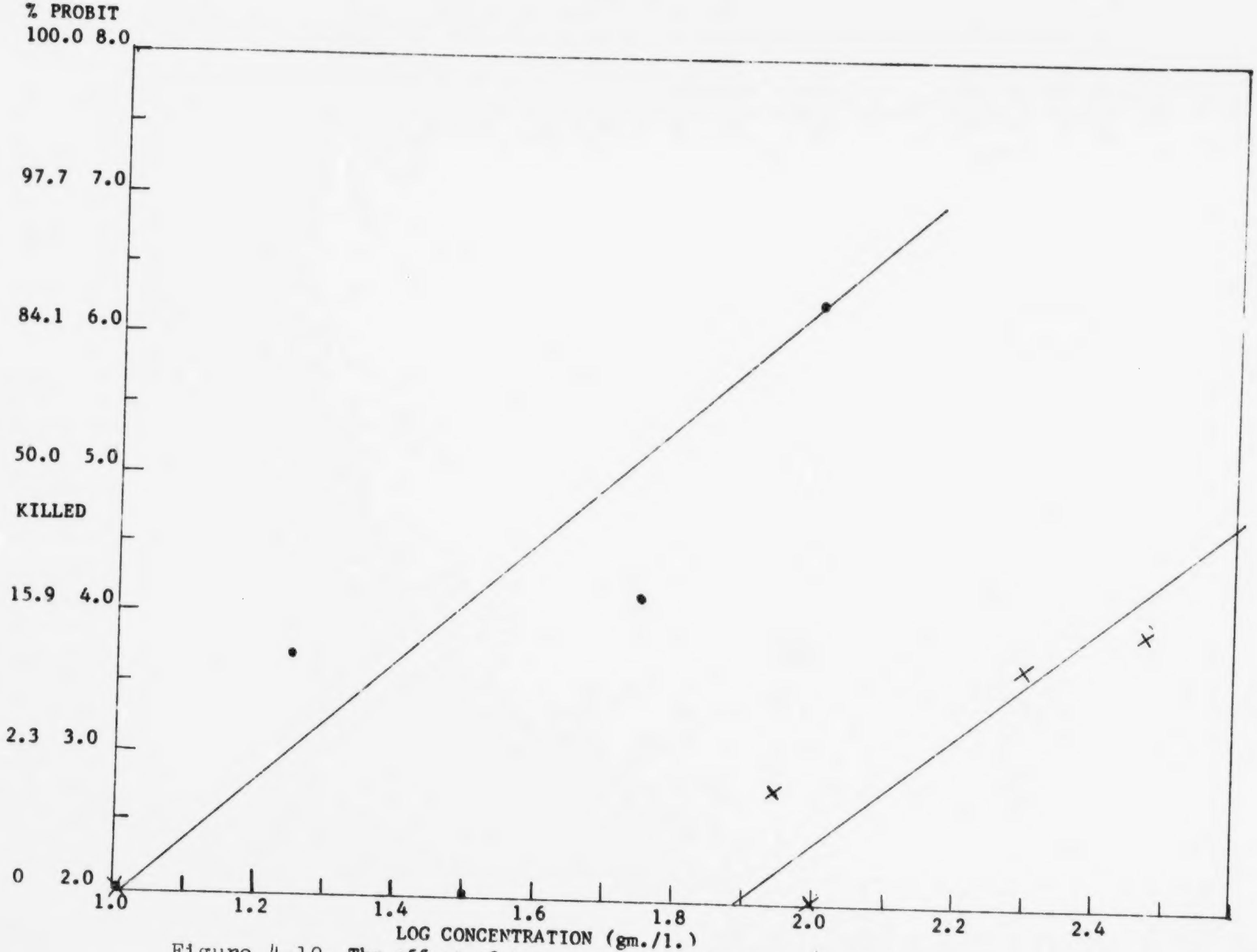

Figure 4-19. The effect of temperature on the toxicity of suspensions of Kingston silt to sheepshead minnows, *C. variegatus* after 24 hr. at (•)19° C., (X) 12° C.

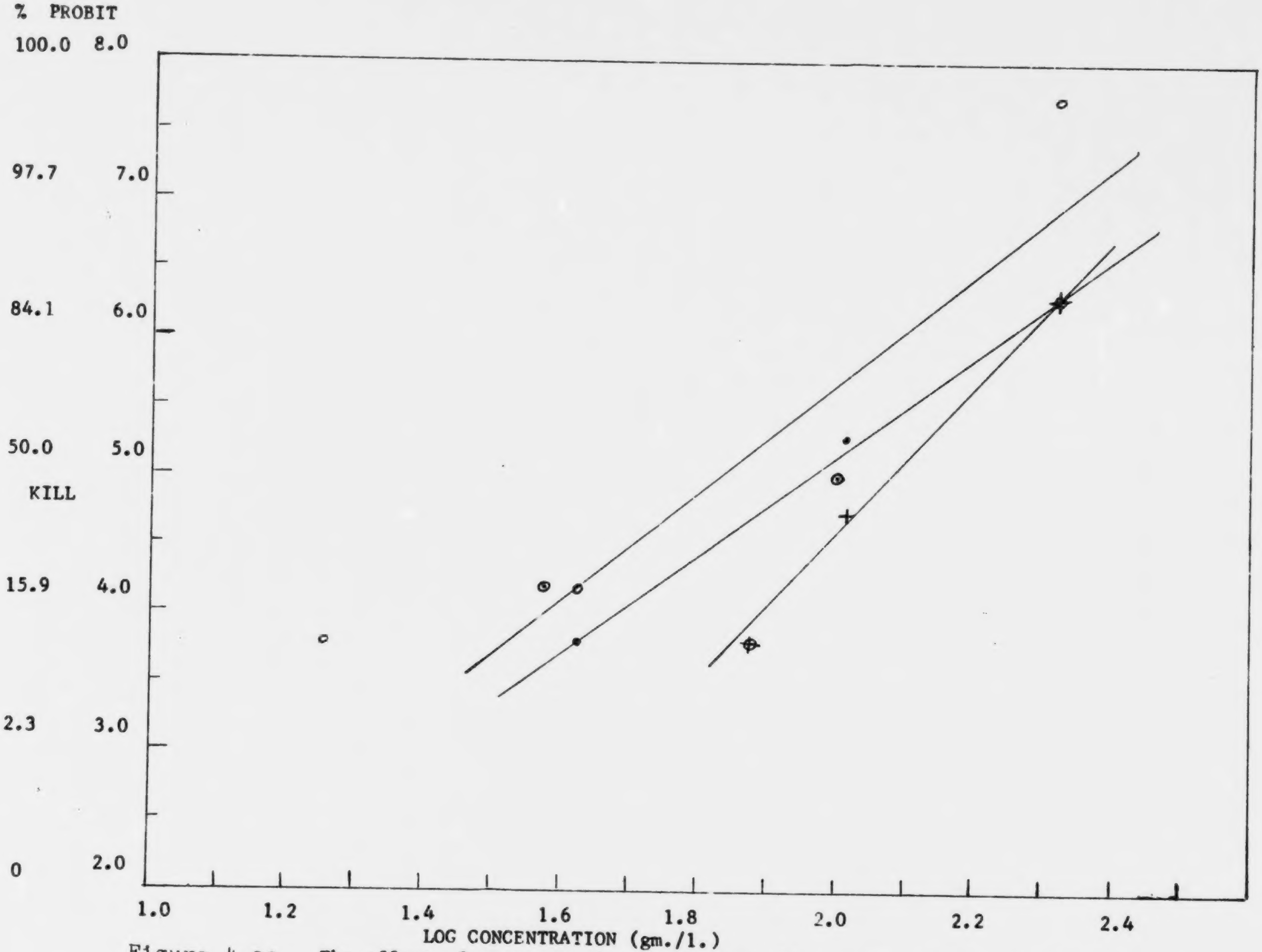

Figure 4-20. The effect of exposure time on the mortality among cunner, T.adspersus in suspensions of Kingston silt at 15° C. (+) 12 hr., (•) 24 hr. (○) 48 hr.

against the interpolated LD_{50} value for each exposure time within the range of exposure times used in this study. It is not safe to extrapolate beyond the data points in either direction. Studies on temperature tolerance and resistence to chemical toxicants of fish often reveal an inflection point in the exposure time LD_{50} curve. This point defines a critical temperature or concentration beyond which the animal no longer responds in a linear fashion. The location or even the existence of such an inflection point has not been demonstrated in this study but the possibility of its existence should be considered when evaluating the results of these exposure time studies.

Most experimental bioassays were run for 24 hours, and comparisons between species, materials and test temperatures are all based on the results of 24 hour bioassays. This 24 hour exposure period was chosen because the use of a longer exposure period required the changing of experimental suspensions to prevent the accumulation of waste products. In addition, because of the opacity of the suspensions the test aquaria had to be emptied to check for mortality, subjecting the survivors to extra handling.

Species Difference in Resistence to Particle Suspensions.

There are real differences in the ability of the different species tested to survive in suspensions within a given range in concentration at a given temp. Figure 4-21shows a comparison of the response curves of four species of test animal to suspensions of Kingston silt over a temperature range of from 12 to 15°C. LD_{50} concentration values span at least two orders of magnitude. Fig. 4-22 demonstrates observed differences in the responses of two different species to incinerator residue suspensions. The same rank order of susceptibility between A. quadracus and T. adspersus occurs in both residue suspensions and suspensions of Kingston silt It would be unsafe to apply the results obtained from one species to other untested species.

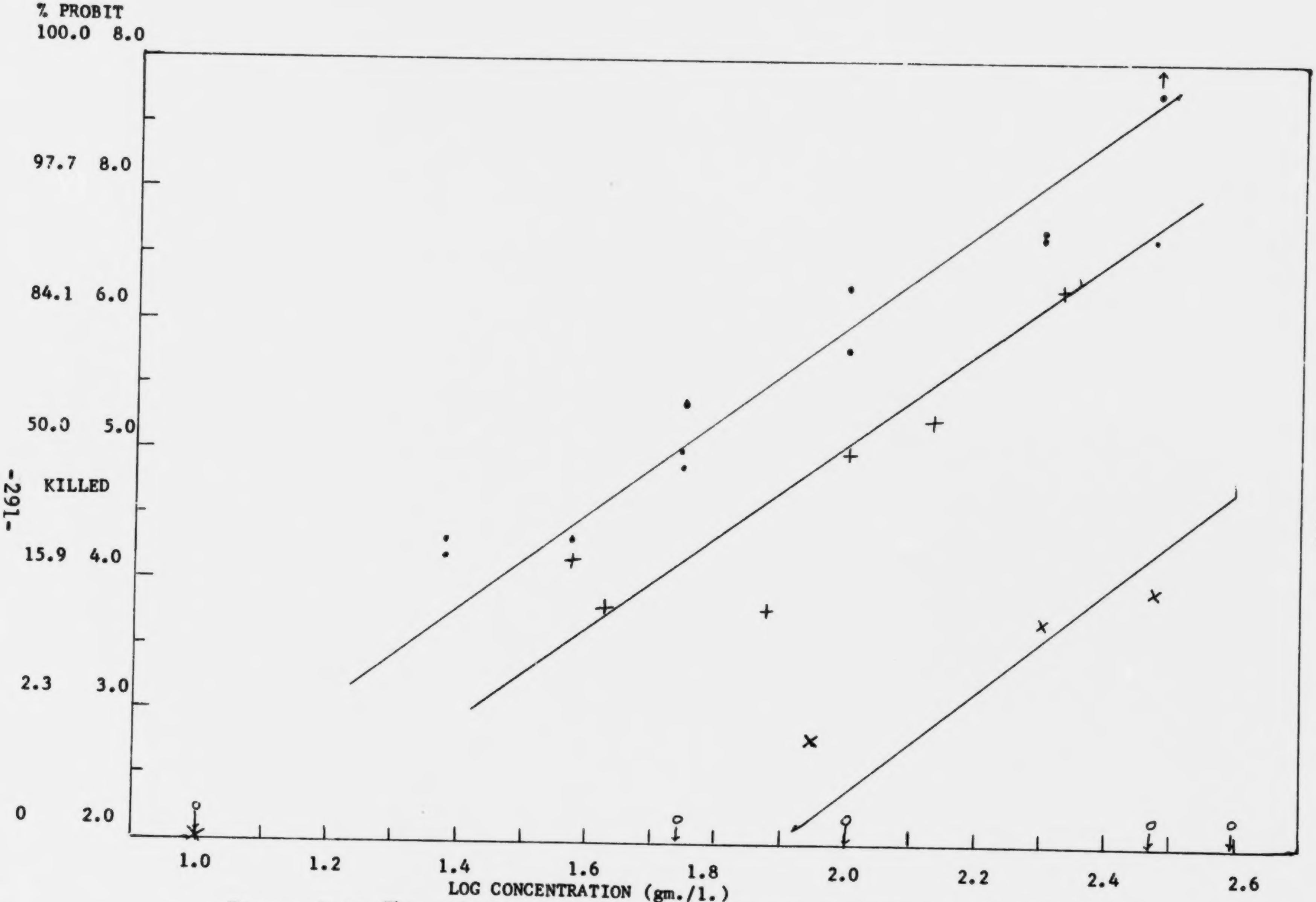

Figure 4-21 The relative toxicity of Kingston silt suspensions at 12-15°C. to four species of estuarine fish, (·) Apeltes quadracus, (+) Tautagolabrus adspersus (×) Cyprinodon variegatus , and (○) Fundulus heteroclitus , after 24 hr. exposure

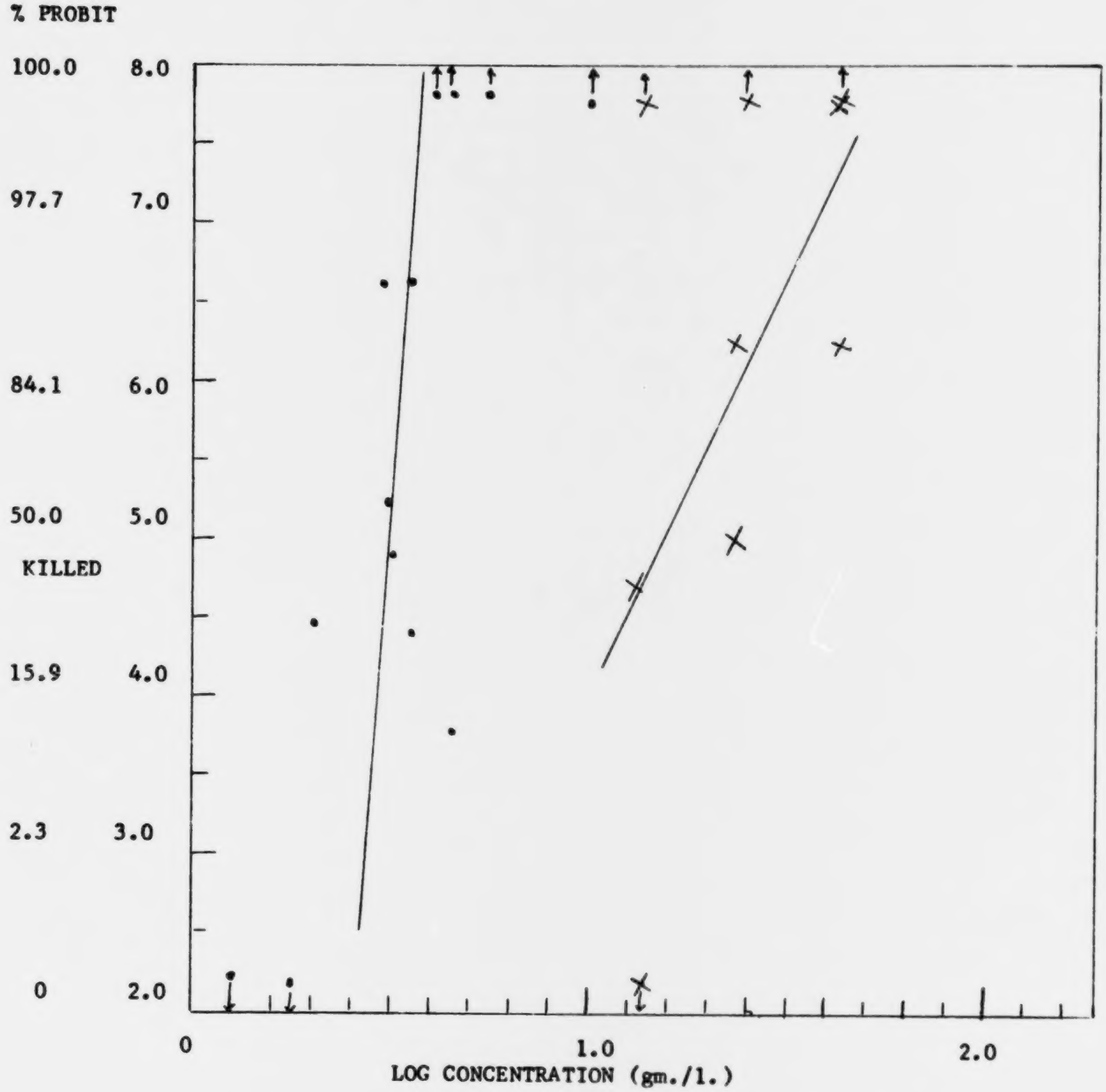

Figure 4-22. The relative toxicity of Incinerator residue in suspension at 12-15° C. to two species of estuarine fish, (•) Apeltes quadracus, and Tautagolabrus adspersus (X) after 24 hours exposure

E. Effects of Particle Size on the Toxicity of Experimental Suspensions

There is an apparent correlation between the toxicity of a given suspension and the median grain size of the particles comprising it. The cumulative size frequency distributions of the four particulate materials used in most bioassays is given in Fig. 4-12. Fig. 4-23 compares the rank order of toxicity observed in experiments using T. adspersus, A. quadracus and F. heteroclitus with the ranks of particulate materials in terms of their median grain size. In experiments using T. adspersus and A. quadracus the particles having the relatively larger median grain sizes exhibit the greater relative toxicity. The reverse is true, however, in experiments involving F. heteroclitus. Diatomaceous earth while having a smaller median grain size than Kingston silt is more toxic (Fig. 4-16). In this case, particle size alone is clearly not the only important factor involved.

Effects of Particle Shape on the Relative Toxicity of Experimental Suspensions

The increased toxicity of diatomaceus earth in spite of its smaller grain size suggested that particle roughness or shape might be an important factor. Samples of particulate material used to prepare experimental suspensions were examined under the microscope.

Diatomaceous earth particles consist of fragments of fossil diatom frustules. All are highly angular. Fragments of the lacy siliceous frustules assumed a variety of shapes all characterized by the presence of countless needle-like siliceous projections.

Kingston silt , composed primarily of quartz fragments, had apparently undergone some reworking by wind or water before being deposited in the Kingston area. The particles, though angular, had few projecting sharp edges. Angles formed by the intersection of crystal faces were often abraded and smoothed.

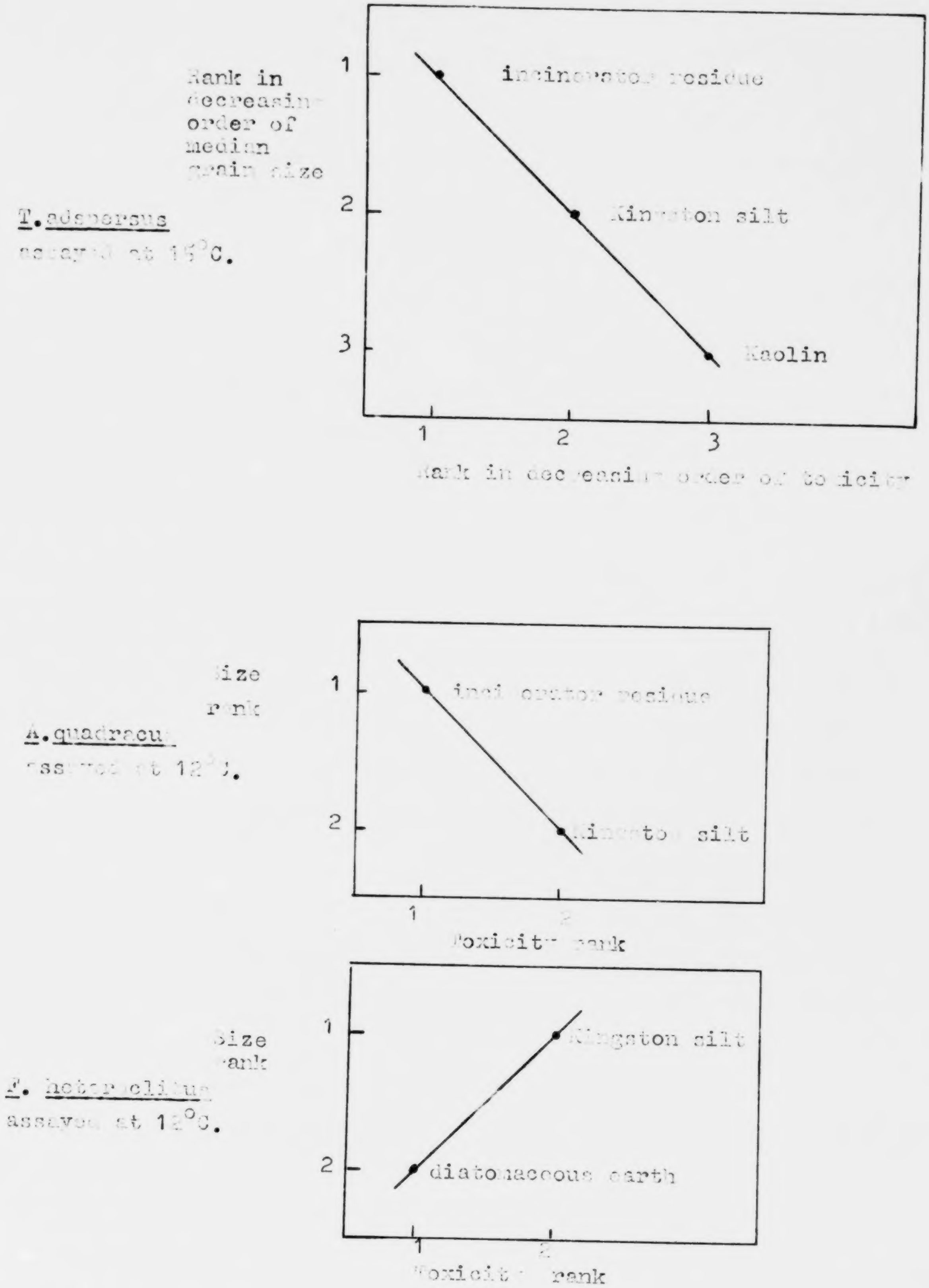

Figure 4-23. Effect of particle size on toxicity.

No individual kaolin particles were examined since their size was beyond the range of the light microscope. As suggested earlier, kaolin particles in sea-water are actually aggregates of individual particles assuming varying sizes and shapes.

Examination of incinerator residue particles of all sizes revealed a uniformity in shape distribution. All particles are angular although they exhibit more of a textural roughness than the actual crystalline angularity as seen in Kingston silt particles. Residue particles smaller than 62 microns contained a small proportion of identifiable fragments of glass or porcelain-like material. Most particles were spheroidal or roughly disk-shaped and looked like bits of clinker. Individual particles often had a pockmarked appearance and in many cases several particles were found fused together into an irregular aggregate.

Several experiments were run to provide data for the evaluation of the importance of particle shape to the toxicity of experimental suspensions. The results of these experiments using A. quadracus are given in Figure 4-24. The concentration of all suspensions used in this experiment was 10 gm. per liter. Animals exposed to suspensions of powdered glass all died within 24 hours. This material was composed of highly angular splinters of glass. Repeated assays at the same concentration yielded the same results. Diatomaceous earth showed a similar high toxicity. Suspensions of glass spheres proved only slightly toxic. Still less toxic was the suspension of activated charcoal. The results of these experiments demonstrates that angular particles in suspension are more toxic than smooth particles.

The Etiology of Mortalities Observed in Experimental Suspensions

At least part of the mortality that occurs among fishes in particle suspensions can be attributed to interference if not injury to the branchial epithelium by

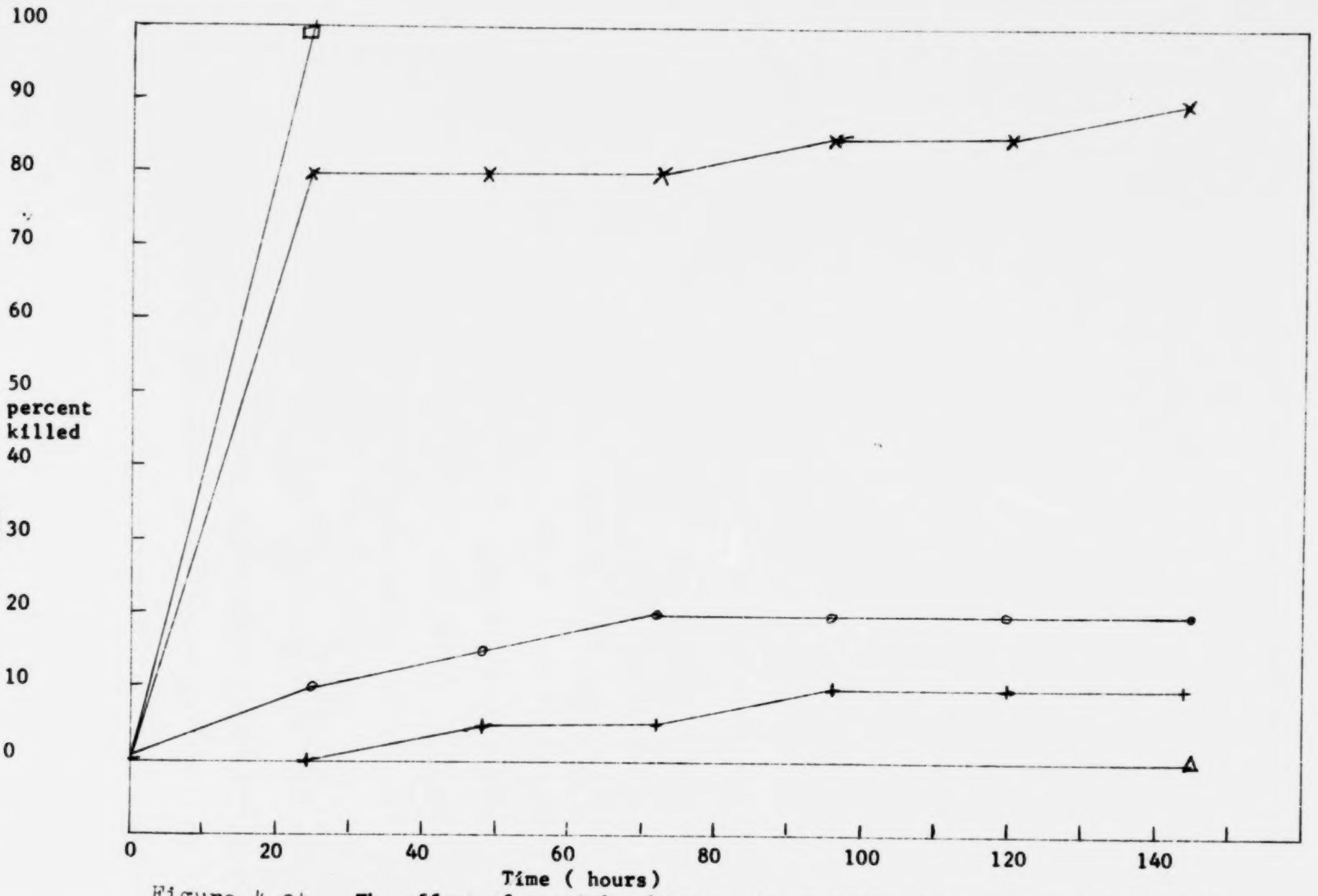

Figure 4-24. The effect of particle shape on the toxicity of suspensions of 10 gm./l. concentration of, (▫) ground glass, (×) diatomaceous earth, (○) glass spheres, (+) powdered activated charcoal, (△) control to _A. quadracus_ tested at 12.5° C.

rough or angular particles in suspension. The larger and rougher the suspended particles are the more toxic the suspension becomes. There is, however, evidence that other factors are involved as well.

Fish which have died in suspensions of mineral solids are generally found with their gill filaments matted and clogged with particles from the suspension. Fish which have survived exposure to suspensions show no sign of partial clogging. The respiratory surfaces appear to be protected with a copious secretion of mucous. Studies by McLeod and Smith(18) reveal an increase in the number of mucous cells in the gill epithelium of fathead minnows (*Pimephales promelas*) exposed to sublethal concentrations of wood fibers in suspension, indicating that mucous production is directly or indirectly responsive to changes in the concentration of suspended solids in the test medium. It is common to see fish trailing ropy secretions of mucous from their opercular cavities. These secretions are colored with particles from the suspension. It is not clear whether death occurs when this protective mechanism breaks down or whether as death approaches mucous secretion is reduced. The apparent absence of fishes with indications of partial clogging lends credence to the latter view.

The presence of particles in suspension seems to affect the fishes' ability to remove dissolved oxygen from the water. It has been suggested that suspended particles may cause a reduction in the amount of oxygen that can be held in dissolved form in water at a given temperature. Measurements of oxygen concentration in experimental suspensions were made using an oxygen electrode. Dissolved oxygen values measured at the beginning and the end of a series of experiments were averaged and the average plotted against the observed percent kill in each aquarium. The result and regression line had a slightly negative slope. The correlation coefficient was 0.54 indicating no clear relationship between the measured oxygen concentration and the percent kill. None of the measured oxygen values in this series fell below 4.0 ppm.

In spite of this uncertain relationship between mortality and measured oxygen concentration, survival increased in suspensions into which supplementary pure oxygen was bubbled through an air stone. This addition of pure oxygen raised the measured oxygen level only one or two ppm.Figure 4-25 shows the results of these investigations.

Retaining screens were placed in all bioassay aquaria to keep the animals in contact with the suspension. Fish showed signs of distress in suspensions of a much lower concentration than was needed to kill them. Wallin(12) describes a series of behavioral reactions of fishes near death in concentrated silt suspensions. Many of these symptoms were noticed in the course of the present studies. Fishes tended to gulp air at the surface when placed in even sublethal concentrations.

Access to the surface affects the fishes' ability to prolong life in incipiently lethal suspensions. Fig. 4-26 shows the results of bioassays using A. quadracus which demonstrated that access to the surface increases the fishes' ability to survive in particle suspensions. Fish are physiologically bound to an aquatic existence; gulping air at the surface is a mechanism for "buying time" in a suspension which would ultimately prove fatal. Fish at the surface show all of the symptoms of anoxia. Animals placed in vacuum degassed water exhibited identical behavior.

In studies of the effects of suspended chemically inert wood fibers on the fathead minnow Pimephales promelas, McLeod and Smith (18) noted a reduction in the level of active metabolism and a simultaneous increase in the level of standard or resting metabolism associated with exposure to sublethal concentrations of wood fibers. The authors said that energy expended in additional gill cleaning reflexes increased the animals maintenance energy requirements at the expense of energy available for activity. The problems of survival in suspensions

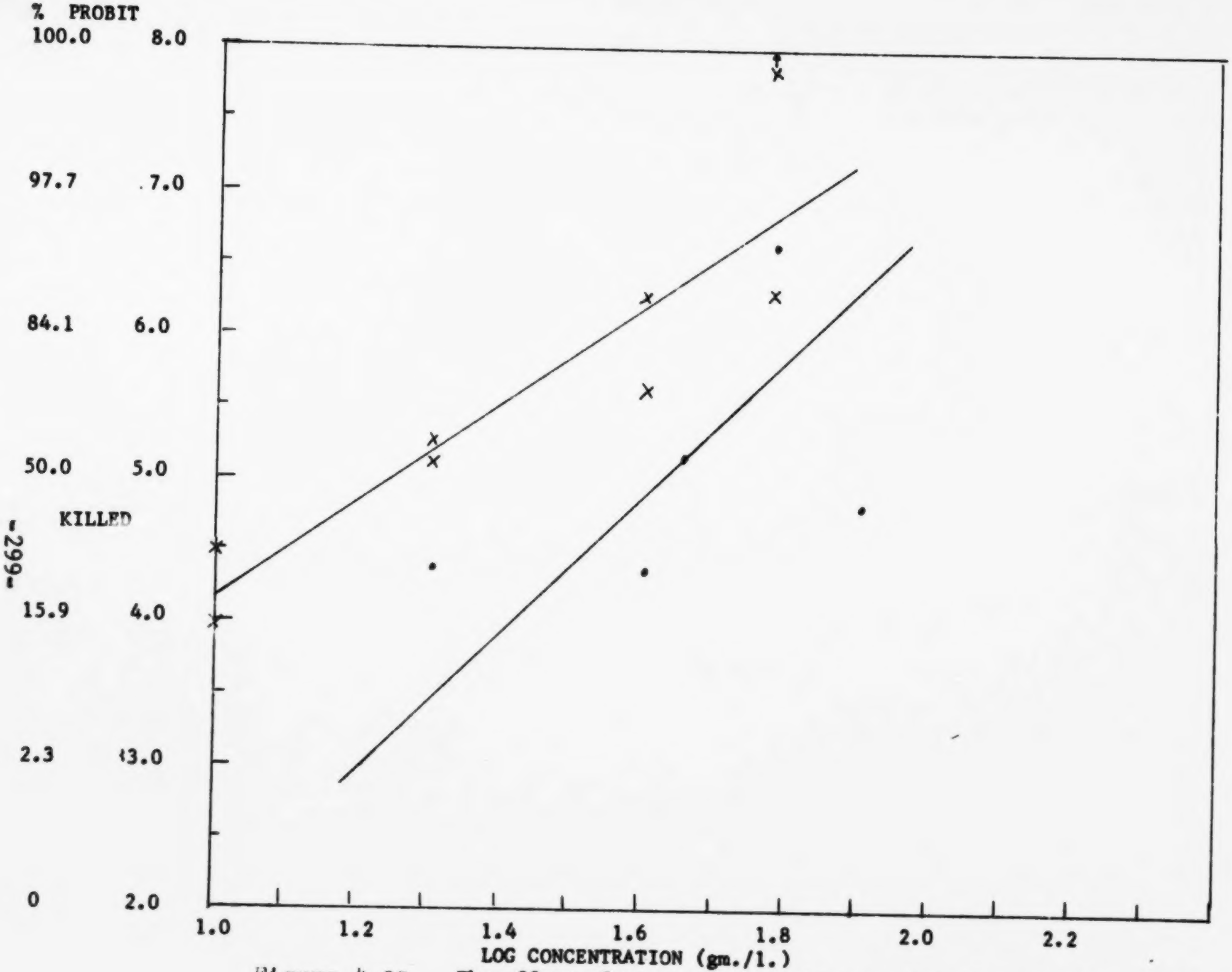

Figure 4-25. The effect of access to the air-water interface on the mortality of A.quadracus in suspensions of Kingston silt after 24 hours exposure at 15-16° C. (X) retaining screens in test aquarium in place; no access to surface, (•) retaining screens removed; access to surface

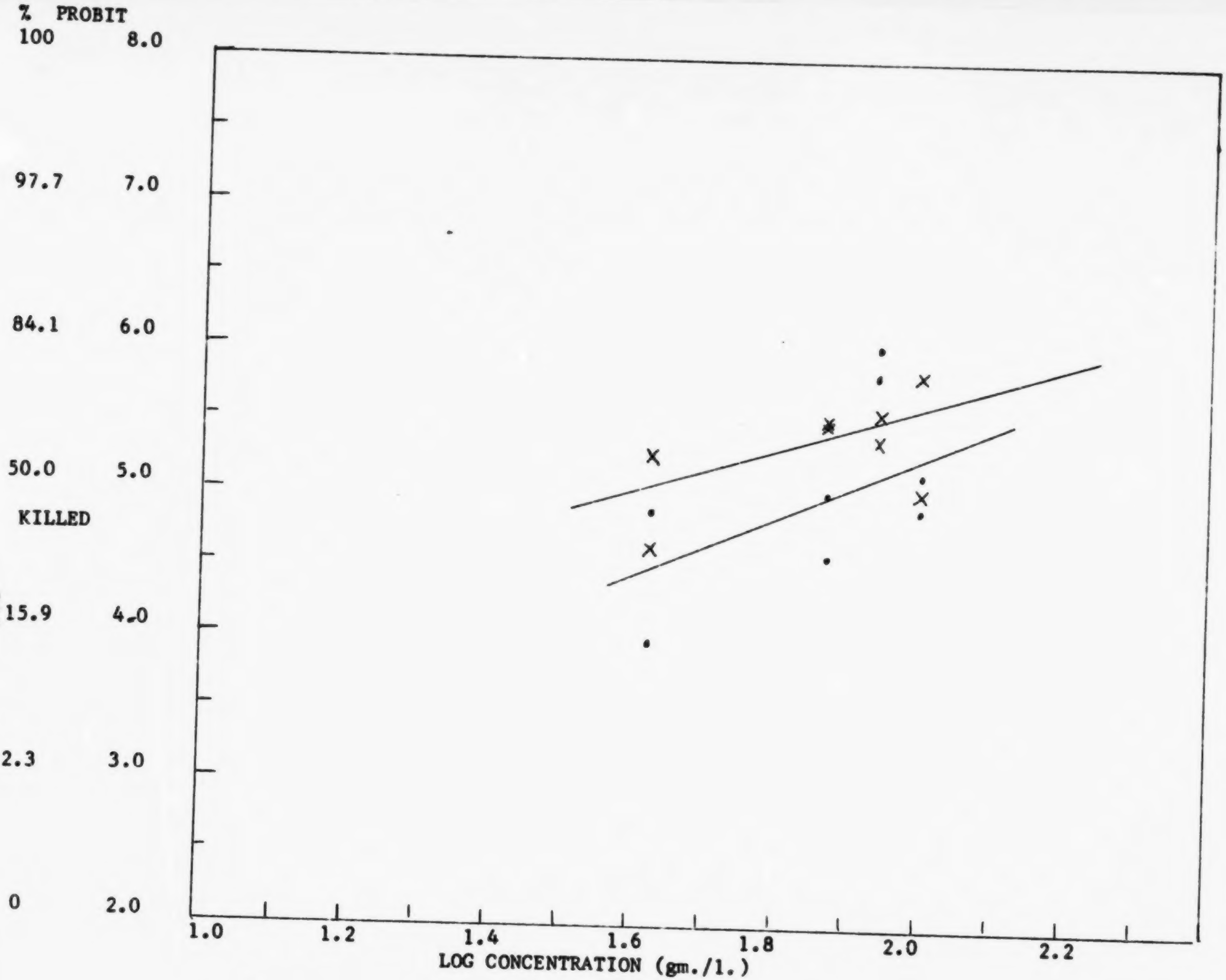

Figure 4-26. The effect of bubbling pure oxygen into experimental suspensions on the mortality of T. dispersus after 24 hours exposure to suspensions of Kingston silt at 21-24 C. (•) normal aeration plus pure oxygen, (X) normal aeration alone

of wood fibers and those encountered in suspensions of mineral are probably quite similar.

The determination of the relative importance of oxygen deprivation through increased maintenance requirements, of gill clogging and of the role of direct gill damage by angular particles must await further study. All may be parts of a single syndrome.

F. Summary and Recommendations

Incinerator residue was found to exhibit a greater apparent toxicity when in suspension than other materials tested. The toxic nature of the residue suspension is attributed primarily to the extreme surface roughness and angularity of the individual particles themselves. These studies revealed that the apparent toxicity of mineral particles to the experimental animals used increased with increasing exposure time and with increasing temperature. Different teleost species exhibited different degrees of susceptibility to mortality in particle suspensions.

All of the species tested survived what must be considered high concentrations of suspended particles. Even the lowest particle concentrations used produced suspensions which were virtually opaque. As another frame of reference, studies by Bond and Meade(19) to determine the concentrations of suspended mineral grains in Chesapeake Bay revealed concentrations of approximately 1 mg/l. in bucket samples taken at the surface at the mouth of the Susquehanna river. The standard exposure time used in the present study was 24 hours. Whether or not hydrographic conditions exist which could maintain toxic concentrations of residue particles for 24 hours at a time is a question which is beyond the range of this study.

V ECOLOGICAL ASPECTS OF THE DISPOSAL OF INCINERATOR RESIDUES IN THE SEA

Christopher Martin

Ocean waters cover more than 70% of the surface of the earth. While much of this area is still beyond easy reach of man, a considerable part lies adjacent to the continents. Access to the marine environment is readily available to large populations concentrated in vast urban centers. The enormous volume of the ocean and its apparent capacity to assimilate substantial quantities of man-generated wastes has encouraged widespread exploitation of these characteristics. Offshore disposal activities have ranged over a wide spectrum including sewage, chemicals and other industrial wastes, explosives, radioactive materials, incinerated refuse and a host of minor waste substances. Attempts have been made to evaluate the significance of some of these activities(20,21,22,23). The complexity of the relationship which exists in the ocean ecosystem and the lack of detailed factual knowledge of many facets of its mode of operation limit our ability to evaluate accurately the effects of such activities. Disposal of wastes in offshore waters continues at increasing rates under pressure of coastal urban expansion and, while inadequate scientific knowledge of the consequences is deplored, such practices continue to offer attractive solutions to major problems of urban life.

Increased concern for maintaining and restoring the quality of the environment has stimulated research in the areas of prime concern. Since stresses upon the marine environment from pollutants are certain to increase, the need for guiding principles based upon sound ecological investigations of both biotic and abiotic aspects of the ecosystem become more pressing than ever. Such considerations were among those which motivated the investigation of the biological effects of residue from incineration of municipal solid wastes and the studies of residue deposition and stability on the ocean floor. Clearly, comprehensive coverage of such a large unit of the marine environment could occupy the attention of a full team of biological and physical oceanographers for a substantial period. Through a study of potential toxic effects of the incinerator residue itself and of the uptake of toxic metals by selected marine species, some probable problem areas have been indicated.

It is helpful at the outset to sketch in the broad outlines of the ecosystem. We need to understand the general characteristics of the localities which are likely sites for disposal activities. Economic factors will surely influence selection as will coastal configuration, bottom topography, meteorological and other considerations. This will mean that we will be dealing with continental shelf areas approximately 32 kilometers offshore in water depth in excess of 60 meters. While such areas are essentially coastal, the influence of the open ocean may be considerable. Physical conditions including wave and current patterns, temperature and salinity profiles will be subject to oceanic factors. Such areas frequently constitute the primary fishing grounds for both commercial and sport species as a result of high levels of primary productivity (photosynthetic fixation of carbon by microscopic algae). The large populations of fishes characteristic of these regions are supported by a larger biomass at lower trophic levels in the energy pyramid. Thus, both primary producer (microalgae) and primary consumers (zooplankton) are present in enormous numbers. These latter, weak-swimming, animals of many species typically show a number of larval stages in addition to eggs and adults. Such juvenile members contribute significantly to the size of a population. Similarly, among the larger invertebrates and fishes, larval stages are encountered in both sediments and overlying waters of these neritic areas. It is frequently observed that the niche occupied by the larva of a species may be quite distinct from that of the adult. Thus, the biotic or living component of a continental shelf, neritic region is highly complex, consisting of many active species in all developmental stages. Energy relations, trophic levels, and food chains or, more properly, food webs, are not easily characterized.

Many aspects of these relationships are known only in outline form. Controlled laboratory studies of nutrition have been restricted to a relatively small number of well-known, hardy species. Complicating this problem is the fact that many larval stages have not, so far, been associated with particular adult species. Food webs are imperfectly understood. Information on life cycles of most offshore species is extremely fragmentary. Behavioral aspects, i.e., breeding habits (courtship, spawning), migratory movements both vertical and horizontal, to name a few essential activities, are even less well documented. Response to normal physical and chemical characteristics (temperature, salinity, oxygen changes) of the environment are areas of fragmentary knowledge, total blanks for the majority of species. Thus, one can readily understand the hesitation shown by most ecologists in attempting to relate cause and effect in marine situations or to generalize to the ecosystem as a whole from data derived from a few selected species. How many parameters must be included to assure a meaningful answer? For example: can the absence of clearly indicated toxicity of incinerator residue to winter flounder (Pseudopleuronectes americanus) be taken as representative of its effect upon other similar benthic fishes, the soles, plaices, halibut? Can we assume that the delicate planktonic larva of the quahaug (Mercenaria mercenaria) will be as comfortable in residue extract as its parent seemingly is? Both quahaug and scallop (Pecten magellanicus) are bivalve mollusks yet they respond quite differently to exposure to the residue. The basis for such differences are not understood but their existence suggests something of the difficulty of extrapolating from one species to another. As puzzling as such observation may be, their exploration appears to be within reach. Consider, however, such subtle matters as the effects of incinerator residue on development of reproductive maturity, courtship rituals in fishes, longevity or schooling behavior, vision, etc. Minor changes in any of these developmental or functional activities may have far-reaching effects. While such effects may be sub-lethal for the individual they may constitute a major catastrophe for the ultimate perpetuation of the population. Survival of an affected individual can ultimately be more detrimental to the species than sudden death from toxic influences. Genetic damage, even less easily detected, may compound these long-term hazards.

The foregoing comments have dealt largely with problems related to individual species. From the point of view of the ecosystem as a whole one must recognize that the components are constantly interacting. The various species present are interdependent in many, sometimes, subtle ways. This biotic component, in turn, is in intimate contact with the abiotic (physico-chemical) component. These are dynamic relationships which tend toward an equilibrium state. Generally speaking, the ecosystem exhibits homeostasis, a self-regulating stabilizing process. This resilience of the environment which brings it back to equilibrium after a disturbance is a striking feature, well exemplified by the ocean ecosystem. However, the limits of this resilience are ill-defined or unknown but must be regarded as finite.

Problems of eutrophication, excessive enrichment, of lake waters are examples of ecosystems which man has pushed beyond the limits of their homeostatic mechanisms. Similar problems have been observed in some estuarine regions where a dynamic equilibrium condition may never be re-established(24).

In light of these considerations, what can be said about the probable effects of marine disposal of incinerator residues?

Is the complexity of unanswered questions so formidable as to prevent any kind of appraisal from limited tests? What will be the likely pathways of components of the residue? If they unbalance the natural system, what areas of the ocean surface or bottom and what volume of intervening water masses will be affected? How long will the effects persist? What populations can expect to feel the initial effects and will the same population be exposed over sustained periods?

Accurate predictions concerning the consequences of marine disposal of a particular kind of waste are obviously difficult, if not impossible, to make in light of present limited knowledge of the marine ecosystem. The need for such predictions is, however, so pressing that it is essential to assess all available information in a search for reasonable opinions on this matter. In the absence of full-scale operations involving the disposal of incinerated municipal wastes it may prove helpful to examine the experiences of disposal practices involving other types of waste materials as an indication of the kinds of effects which might be expected. In so doing, it is essential of course, to keep in mind the fundamental differences between waste materials of different kinds, thus avoiding the dangers of attempting to extrapolate directly from one to the other. With such reservations it should be possible to draw some useful conclusions. Although marine disposal practices of a variety of kinds continue to increase, few have been subjected to critical examination in relation to their effects upon the marine environment. In this regard, it should be noted that the ecological effects which have been established through acceptable scientific investigation may be clouded by claims based upon other generally non-scientific reports. Such reports may, in fact, reflect the actual situation, but because they remain unsupported by controlled observations must be accepted with care in the final analysis.

Waste disposal practices in the marine environment have one feature in common, namely, that introduction of the waste material creates a new set of environmental conditions in the sea water and sediments which will persist for varying periods depending upon the physico-chemical nature of the materials released, their concentrations and rates of disposal, the "buffering" capacity of the accepting waters and the many oceanographic and marine biological characteristics of the disposal area. In the case of repetitive or continuous release of a particular kind of foreign substance into the ocean one might expect an equilibrium to become established within a prescribed area where the counterbalancing forces are maintained at uniform strength through natural compensating mechanisms (i.e., dilution, dispersal, sedimentation, chemical bonding, biological cycling). Over extended periods, however, such an equilibrium would tend to shift as the waste itself took on new characteristics and as the accumulation of some components of the waste material began to create new conditions at the disposal site.

When viewed from this perspective it becomes apparent that the major questions to be answered by ecologists center on the nature and scope of the induced changes. They must try to predict what kinds of modifications will occur and how dramatic they will be in terms of their effects upon the ecosystem as a whole. These questions must be answered in terms of both space and time. Spacial considerations derive from the recognition of a finite (albeit, vast) ocean system which at present serves a number of purposes and which in future years can be expected to serve many new, hopefully compatible, ones. Temporal matters fall into two categories, those concerned with the general long-term environmental effects and those related to the time-dependent aspects of natural processes, for example, generation times, growth rates, turnover rates, residence times of chemical elements.

The widely diverse nature of the phenomena involved touch upon many disciplines from microbial metabolism through animal physiology to the biology of populations and the study of animal behavior. Chemical and physical oceanographers and marine geologists will hopefully provide the information needed to understand and predict changes in the abiotic (non-living) components of the ocean ecosystem. Computerized simulation models of ecosystems may be helpful(25).

While we do not possess very many answers to the fundamental questions raised, some information is available which bears upon the problem. In addition to extensive theoretical and experimental treatment of many physical oceanographic phenomena and detailed physiological and metabolic studies of some marine species there are a few studies of marine disposal activities which can help in evaluating and predicting effects of large-scale projects.

It may prove helpful to review some of these in order to demonstrate their usefulness in this regard.

Among the first attempts to apply modern marine biological and oceanographic methods to the study of a disposal practice was that of Redfield and Walford(26,27) concerning the dumping of titanium plant wastes in the waters of the New York Bight. A program sponsored by the National Research Council was carried out by the Woods Hole Oceanographic Institution and the U. S. Fish and Wildlife Service to assess the effects of the release of 4000 tons/day of a solution containing 11% each of ferrous sulfate and sulfuric acid. Detailed water sampling was performed in order to define the dimensions of the polluted water mass as the waste barge released its cargo. Changes in salinity, pH, oxygen and iron content of the sea water were monitored. It was shown that the sulfuric acid in the waste was rapidly neutralized upon dilution with the sea water in the wake of the barge and that an area encompassing approximately 1/4 square mile was affected. Ferrous iron was oxidized quickly to ferric hydroxide which remained in colloidal suspension. Increased turbidity resulting from this could be recognized for about 8 hours. Oxygen consumption in the formation of ferric hydroxide was minimal and return to normal background levels was rapid. No net accumulation of iron in the offshore waters or sediments was detected.

In limited biological studies it was shown that certain zooplankters were immobilized on exposure to the acid-iron wastes but that they recovered when transferred to fresh sea water. No changes in populations of benthic and pelagic fishes were recognizable following dumping operations.

Based upon these findings and some additional hydrographic studies(28) Redfield and Walford(20) concluded that: "...the procedure employed by the National Lead Company in disposing of the wastes from its titanium plant is entirely proper. The operation should not be discouraged unless some new facts justify a contrary opinion."

A review of the situation in 1958 under the auspices of the Public Health Service(29) exposed conflicting views concerning the effects on the fishing industry of this waste operation. This report further cited the need for additional detailed study and noted that "...for all practical purposes, this (disposal) area has been eliminated as a sports fishing area", even though harmful effects on the fishes themselves from the disposal activities had not been conclusively shown. In more recent evaluations Westman(30) pointed to beneficial effects of shading by the ferric hydroxide precipitate and Gunnerson(31) confirmed that the disposal site is presently a productive fishing area.

The New York Bight studies support the general conclusion that the marine environment possesses considerable assimilatory capacity. Roughly 4000 tons per day of acid-iron waste materials were either neutralized by the sea water or otherwise reacted with it to form a precipitate which was relatively insoluble, of low density and readily dispersed. During the period July 1948 to August 1949, 40,000 tons of iron in this waste were released in the disposal area without significant increase in the total iron content of the receiving waters or sediments.

The magnitude of this dumping operation is itself impressive and the reported absence of detectable lasting deleterious effects is notable. In this study, the investigators laid great stress on the importance of their oceanographic analyses, particularly in connection with the pattern of circulation in the disposal area and contiguous waters. While considerable seasonal variations in local hydrographic conditions were observed, it was, nevertheless, possible to estimate how the waste-containing waters would behave.

Unlike acid-iron wastes, residues from the Boston municipal incinerator are largely (more than 98%) insoluble and consist predominantly of materials which are denser than sea water . For this reason the accumulation and fate of large amounts of unchanged residue becomes more significant than changes in the chemical make-up of the receiving sea water. At a projected dumping rate of 500 tons per day (Boston) one would expect about 7 to 10 cm of residue to accumulate per square mile per year assuming uniform spread and sedimentation of all residue particles. A more likely situation would involve uneven deposition with compaction and shifting deposits resulting in a dump having highly variable topography.

With a sediment build-up of such small proportions (0.2 mm per day) the chief question seems to be concerned with the long-term concentration of residue in a more or less restricted area and the slow leaching of some of the chemical constituents.

Among the residue components which might be expected to upset biological balances are the trace metals. In order of decreasing abundance in sieved (12 mm) Boston incinerator residue these are: iron, zinc, lead, manganese, copper, nickel, chromium, cobalt, and cadmium. The accumulation of these trace elements in natural sea water is directly related to their chemical reactivity. Those elements which are most reactive in the bio- and geochemistry of the sea become incorporated most rapidly in the sediments: i.e., their residence times in sea water are short. Of special importance in the cycling of trace metals is the selective enrichment of certain metals by marine species. It is well-known that such metals as copper, zinc, and nickel may be concentrated by factors of 100 to 100,000 by some marine organisms. Moreover, some metals form very stable complexes with organics from which they are not easily removed so that such elements would tend to remain in the organic cycle until deposited in the sediments(32). Thus, it is likely that trace metals in incinerator residues would move rapidly into biological cycles and through certain food webs these potentially toxic metals would be widely distributed in marine animals. There is, of course, a public health aspect to this since some of these animals are links in short food chains involving man (i.e., plankton → shellfish → man).

Whether or not the toxic properties of these metals will affect marine populations and/or man will depend on the tendency of benthic or other species to concentrate significant quantities. Our uptake studies showed increased tissue levels of certain metals in three commercially important species (flounder, scallop, and hard-shell clam) exposed to incinerator residues. In the case of the scallop (Pecten magellanicus) the residue was shown to possess toxic properties as well. No causal relationship between metal uptake and toxicity was established in these studies. Both rate of accumulation and tissue levels of trace elements in marine species seem to be related to environmental concentrations, among other things. Pringle et al.(33) have shown, for example, that a two-fold increase in environmental lead results in a doubling of both uptake rate and tissue concentration in the eastern oyster (Crassostrea virginica) and soft-shell clam (Mya arenaria). While certain metals like copper and nickel play fundamental roles (i.e. enzyme activation) in the biochemistry of such animals, prolonged exposure to low environmental levels may be toxic.

Applying such information to the incinerator residue situation one is led to the conclusion that both stimulatory and toxic effects may be encountered with respect to trace metals. In the absence of distorting effects of currents and wave action it is possible that the environment of a residue deposit would consist of an intergrading series of concentric zones where trace metal concentrations would be most damaging in the central zone but would decrease rapidly outward. It is conceivable that a zone of increased biological productivity and standing crop would be established which would merge rapidly with the background conditions.

Evidence for such zonation in marine waters has come from biological studies of the mainland shelf of the California coast (34,35). There it has been seen that both primary productivity and benthic populations adjust to the effects of sewage effluents in this way.

In these studies, normal populations were found to be disrupted in the areas of effluent discharge. The stress imposed upon the individual organisms manifests itself in changes of community structure of benthic animals. Species diversity is lowered as a few tolerant types of organisms become established and increase in number to the exclusion of other forms. As a rule the trend in such communities under stress is toward species of smaller size. This means an increase in microorganisms and some of the smaller invertebrate animals. Very little is known about the stability of marine populations in the vicinity of disposal sites. However, in other California studies maximum "flatfish" population in a sewage-effluent-enriched zone moved closer to the outfall following a reduction in "solids loading" in the effluent(36). Such changes suggest that equilibrium conditions may be transient and will be modified with changes in the rate of introduction of the waste material as well as in the physicochemical nature of the waste itself.

It has been pointed out in discussions of the disposal of radioactive wastes that special caution is required owing to the very long lives of some radionuclides. Once accumulated in the ocean in harmful concentrations their effects will diminish slowly(37,38). It may be appropriate to consider this matter in connection with incinerator residues. While the long-term toxic effects of trace metals on marine plants and animals are not well understood, it is quite clear that deposition sites will become foci for the concentration of large quantities of these elements which will be released slowly into the surrounding waters. Deleterious effects from these relatively insoluble trace metals may continue long after a decision has been reached to stop disposal activities. The danger lies in being unable to predict accurately the effects before critical concentrations are reached. In this sense, the effects are irreversible.

One final consideration should be noted, namely, that waste disposal in the ocean can be regarded as a highly selective erosion of the land in which man controls and directs the process. The crucial question appears to be one of the relative importance of human activities of this sort and the natural processes involving wind and water action which continuously introduces substances into the sea. In this regard, both rate of disposal and total waste load are variables which will have significant, immediate and long-term effects upon the receiving ocean environment. From the point of view of the biotic component of the sea, natural erosion generally occurs at a rate compatible with the ability of resident plants and animals to adapt to the changing environment, whereas, waste disposal may place unusual stresses on living systems over relatively brief spans of time. However, it is important to recognize that total quantities of substances entering the sea from natural and man-generated sources may, in fact, be of comparable magnitude. For example, Redfield and Walford (26) found that half of all the iron released each day into the New York Bight had its origin in the drainage of the major river in that area, the Raritan, with the other half coming from acid-iron waste disposal activities. Similarly, it was estimated that the Sacramento (California) River drainage system contributes about the same amount of phosphorous and nitrogen to the ocean as does the Hyperion sewage treatment plant of the City of Los Angeles (35). Even though most present-day river effluents are grossly affected by human activities, having received their dissolved and particulate loads in a variety of ways, nevertheless, such comparisons are indicative of the relative importance of "natural" and "artificial" erosion.

The implications of the disposal of incinerator residue at sea are numerous and, at best, only partially recognizable and understood. Nevertheless, a few general conclusions may be drawn from existing information.

1. Incinerator residue will dramatically modify the immediate environment. Beneficial effects which may be anticipated include improvement of existing habitats or creation of new ones with respect to particular species while harmful effects will include damage or obliteration of existing habitats of other species.
2. Assimilation of the components of incinerator residue by the marine ecosystems will involve sedimentation, dissolution, biological uptake and cycling, and dispersal. The importance of each of these processes will vary with the particular component of the waste. The role of the biosphere in assimilation cannot be predicted accurately from presently available

information. (The ability of marine organisms to concentrate elements has been studied in very few species and is known to show wide variation among species.)

4. Response of organisms to the presence of incinerator wastes will not be uniform. Species difference may be expected as may differences related to stages in life histories and physiological state of the organisms. Therefore, extrapolation from one species to another or from larva to adult may be very misleading.

5. Toxic effects from residue components (especially heavy metals) will depend upon many factors other than the simple presence of the toxin and a sensitive species. Uptake rates are influenced by associated physiological condition of the organism (i.e., age, reproductive stage) and chemical factors such as concentration and presence of other elements in the environment.

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Section 5-1

OCEANOGRAPHIC STUDIES

Candace Oviatt
Melvin W. First

Introduction

This study is concerned with criteria for the disposal of incinerated residues in the marine environment. Marine waste disposal standards must be accurately defined as population grows, quantities of waste increase and other beneficial uses of off shore waters increase. Experimental sites were selected to determine the fate of residues on the bottom at different depths. No attempt was made to determine the fate of suspended or floating components. These components should be minimal and insignificant if correct incineration processes are followed. Cans and bottles were chosen to represent incinerator residue. Direct observations were made by SCUBA divers in shallow waters and from a small submersible in deeper waters on the movement of these materials. These observations were correlated with current and wave measurements gathered on instrumented buoy arrays and underwater installations. It is hoped that the results of this study will be of value to law-makers concerned with legislation on standards for marine disposal, to the government agency or the industry contemplating residue disposal and that this study will set a precident for oceanographic studies before and during any type of waste disposal in the marine environment.

General Objective

The general objective was to define criteria for an economically feasible dump site which would not conflict with military, commercial and fishing interests, and at which extreme oceanic conditions would not move material significantly from a designated dumpsite area to cause a pollution problem.

Specific Objectives

1. To investigate a shallow water site in an effort to determine the pertinent physical parameters relative to dumping in 15 M.

2. To investigate a deep water site (54 M) at which the effects of pertinent physical parameters would be minimal and where residue could safely be dumped.

3. To measure physical characteristics of both sites; such as wind speed and direction, wave height and period, surface and bottom currents, temperatures and sediment types in order to accumulate information from which the behavior of the residue at the site under all conditions could be predicted.

4. To place marked cans on the bottom at both sites and to make a limited dump of 485 Kg of anthracene dyed residues during the fall of 1967 in order to follow the movements of those materials and to correlate these movements with physical data.

5. To study the benthic communities and to make a general survey of fish life and epibenthic forms in order to assess the effects of residue dumping on these forms.

Location of Experimental Sites

A shallow water site was chosen at latitude 41°21', N longitude 71°32' W, 3.15 kilometers (1.7 miles) south of the Jerusalem shore of Rhode Island in 15 M (50 feet) MLW. This site was selected for the 1967 studies because of its accessibility, its suitability for divers and because it could be kept under regular surveillance from the shore. It will be referred to in this report as the Pt. Judith Station (Figure 5-1).

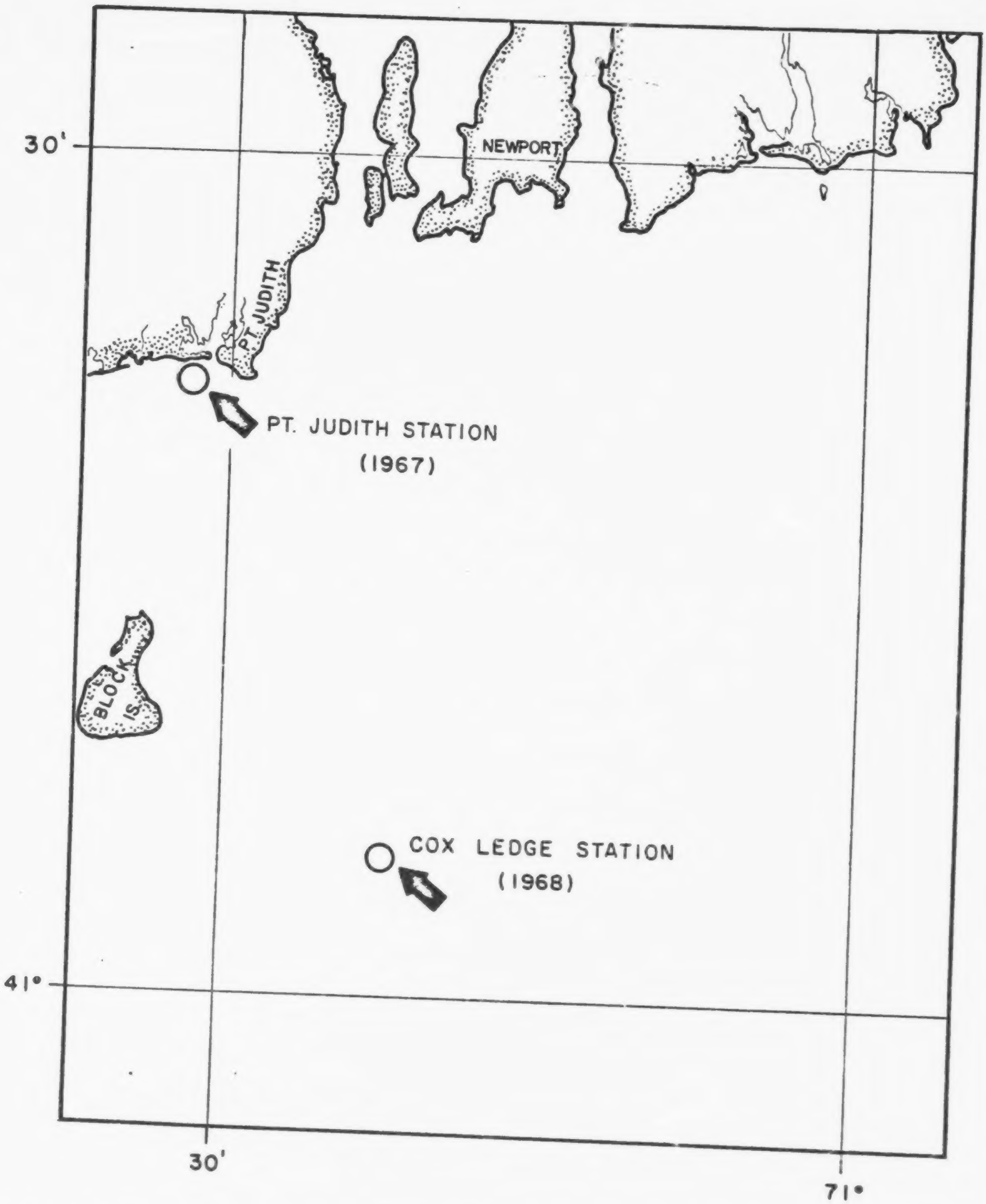

30'
NEWPORT
PT. JUDITH
PT. JUDITH STATION
(1967)
BLOCK IS.
COX LEDGE STATION
(1968)
41°
30'
71°

Figure 5-1. A Chart of the Location of the 1967 Studies at the Pt. Judith Station, and of the 1968 Studies at the Cox Ledge Station.

A deep water site of 54 M (177 feet) MLW was selected for the 1968 studies. This site was located in international waters at latutude 41°04.6' N, longitude 71°22.3' W, bearing 177 degrees, 33.4 kilometers (18 nautical miles) from the east gap of the harbor of Refuge, Pt. Judith, Rhode Island. It will be referred to in this report as the Cox Ledge Station (Figure 5-1). The greater depth of this site decreased the likelihood of residue migration on the ocean bottom but this advantage was **offset** by problems of accessibility, cost of operation, oceanic conditions and fishing intensity.

Studies At The Point Judith Station

Procedures:

Oceanographic data was gathered to measure the physical characteristics of the selected 15 M depth site. A toroidal buoy with a navigation light was used as an instrument platform and as a station marker. A wind speed and direction recorder, two current speed and direction recorders, two temperature recorders and a wave height recorder were used. Table 5-1 indicates the periods of time when these data were collected and details of installation and recovery are given in Appendix 5-I.

A method was sought to estimate the distribution and dispersion of residues in an operational or pilot system. A trend surface analysis of undisturbed sediments was chosen to illustrate the methodology, to provide some information on sediment distribution over the Pt. Judith Station and to attempt to provide some relationship between sediment distribution and water

Table 5-1

A SUMMARY OF MEASUREMENTS AND EXPERIMENTS
AT TWO EXPERIMENTAL RESIDUE DUMPING SITES

Experimental Sites

Date	Point Judith Station	Date	Cox Ledge Station
	MEASUREMENTS		
8/8-11/8/67	Current Measurement	5/31-7/10/68	Current Measurement
10/17/67-1/30/68	Wind Measurement	7/18/68-8/14/68	Current Measurement
8/8/67-9/8/67	Temperature Measurement	7/25/68-5/69	Wave Measurement
9/19/67-11/8/67	Temperature Measurement		
8/31,9/19,9/27	Wave Measurement		
10/23,10/28	Wave Measurement		
10/31,11/16/67	Wave Measurement		
	EXPERIMENTS		
9/67	Sediment Analysis	6/19/68	Dumping Experiments: 3 baskets marked cans and 1 basket broken bottles
	Dumping Experiments:		
8/18/67	a) Marked cans		
10/31/67	b) Marked cans		
10/31/67	c) Marked residue		Submarine Surveys:
8/30,9/8,9/19	Diving Surveys	6/17-19/68	a) First survey
9/27,9/28,10/23	Diving Surveys	7/31-8/4/68	b) Second survey
10/24,10/28	Diving Surveys	9/4-8/68	c) Third survey
10/31,11/1	Diving Surveys	10/21-11/1/68	d) Fourth survey
11/7,11/8	Diving Surveys		
11/16	Diving Surveys		

movements in the area. Procedural details are given in Appendix 5-II.

Marked cans were selected to model incinerator residues for dumping experiments. The reasons were as follows: 1) they are objects which emerge from an incinerator more or less intact, 2) their movement can be followed on the ocean bottom, 3) they would remain intact for the period of experimentation and 4) their presence on the continental shelf would be a type of pollution and a hazard to divers and fishing operations. In the first experiment (8/18/67) 60 individually marked beer cans (20 full of sand, 20 flattened, and 20 round) were placed in a 1 M diameter circle on the bottom. Distance from the center of the circle, quadrants and can numbers were periodically noted by divers. An additional 60 bent and flattened cans were placed on the bottom (10/31/67). Procedural details are given in Appendix 5-III.

In addition, a trial dump of about 485 Kg (1000 pounds) of incinerator residue was made to determine the nature of its distribution and movement on the bottom. The procedures included dying this residue with anthracene, setting out bottom residue collectors, photographing the collectors and measuring the distribution of the residue on the bottom (Appendix 5-III).

Results:

At the Pt. Judith Station, surface tidal currents came in toward 310 degrees and out toward 90 to 100 degrees with velocities up to 52 cm/sec (1 knot) and averaging 26 cm/sec (0.5 knot). Strong winds tended to prolong or diminish tidal flow. The bottom tidal currents came in toward 270 degrees and out toward 130 degrees. Maximum current velocities were about 31 cm/sec; average velocities were 21 cm/sec.

The trend surface analysis of natural sediments from the Pt. Judith Station indicated no trend that was clearly discernible from any of the fitted surfaces. The distribution of sand was apparently affected by local phenomena and the area studied (2.56 kilometers) was apparently too small to permit analysis of a significant trend in particle size distribution in the sediments.

Visual examination of the sediment samples indicated that the majority consisted of a coarse beach sand. Close to the station buoy the bottom appeared to consist of cobbles interspersed with a fine silt clay (see Figure 5-5).On a diagonal several hundred meters to the West and Northwest from the station buoy, beach sand replaced the cobble stones.

An informal description of the epifauna included starfish (Asterias forbesi), winter flounder (Pseudopleuronectes americanus), sand crab (Cancer irroratus), and lobster (Homarus americanus). The infauna consisted of a rather sparse sand community and included several species of amphipods, worms (six different species at one station), tunicates, a small clam (Astarte sp.) and a few sand dollars. Biomass was very low for most stations and consisted of one or two members of three or four species with various worms predominating.

Can Experiments:

The observations made in 1967 on the movement of tin cans at a depth of 15 M (50 feet) along the ocean bottom are summarized as follows:

1) Round and flat cans were not observed to move when the surface tidal current was 38.7 cm/sec (0.75 kt.) and the wave heights were 0.3-0.6 M (1-2 feet).

2) Bent and flat cans have been observed by divers to move back and forth a distance of about 1 M with the passage of each wave when the wave period was about 10 seconds and the wave heights were up to 0.9 M, 1.2 M , and occasionally 1.6 M, as measured by the wave recorder, and the bottom tidal current was 15.5 cm/sec (0.3 kt.). On the other hand, similar cans were not observed to move when the wave period was about 10 seconds and the wave heights were recorded at 0.15-0.31 M (0.5-1.0 feet). The bottom tidal current speed was 15.5 cm/sec (0.3 kt.), the surface current speed was 20.6 cm/sec (0.4 kt.).

3) Round, bent, and flat cans were observed to undergo a net displacement between surveys. During the 13 day interval after the first dump in July, when the waves were not very large at Pt. Judith, 16 round cans moved an average of about 0.15 M/day in the direction N 50° W (the shortest distance from the station to the shore is about 3.15 kilometers (1.7 nautical miles) in the direction N 10° W.) In the 32 day interval after the first dump 20 flat cans moved an average of about 0.3 M/day in the direction N 28° W. Most of this displacement probably occurred during one day of large swell caused by the fairly close passage of Hurricane Doria. Only two of the sand filled cans underwent a net displacement in an 81 day period following the first dump; one moved about 2 M West and the other 3 M North of the starting position.

4) Observations by divers have shown that the movement of tin cans along the bottom depends upon the can shape and specific gravity. For cans of the same specific gravity the order in which they are most easily moved is: (1) round, (2) bent, and (3) flat, as might be expected. And, of course, for cans of the same shape the cans with the lower specific gravity were most easily set in motion by ocean forces.

Trial Dump of Marked, Unsegregated Residue:

Divers observed the residue about 18 M from the center of the dump site in a Southeast direction (Figure 5-2). Figure 5-3 shows the center of the residue and some of the unburned paper which scattered widely and rapidly. A large percentage of the dumped material floated off in a southerly direction (Figure 5-4). Measurements of the residue indicated an east to west distribution of 6.4 M (21 feet) and a north to south distribution of 5.2 M (17 feet). The day following the dump the east to west distribution was 7.3 M (24 feet) and the north to south distribution was 5.8 M (19 feet). Also on the following day in the southeast radius of collectors, there was, at 15.2 M (50 feet), 56.8 gm of dyed material (Figure 5-5), at 30.4 M (100 feet), 1.3 gm of dyed material; and at 60.8 M (200 feet), 1.2 gm of undyed material. No residue was found in any of the other collectors. One week after the dump the residue was distributed 22.2 M (73 feet) in a southeast to northwest direction (Figure 5-6). Two weeks after the dump these measurements had not changed.

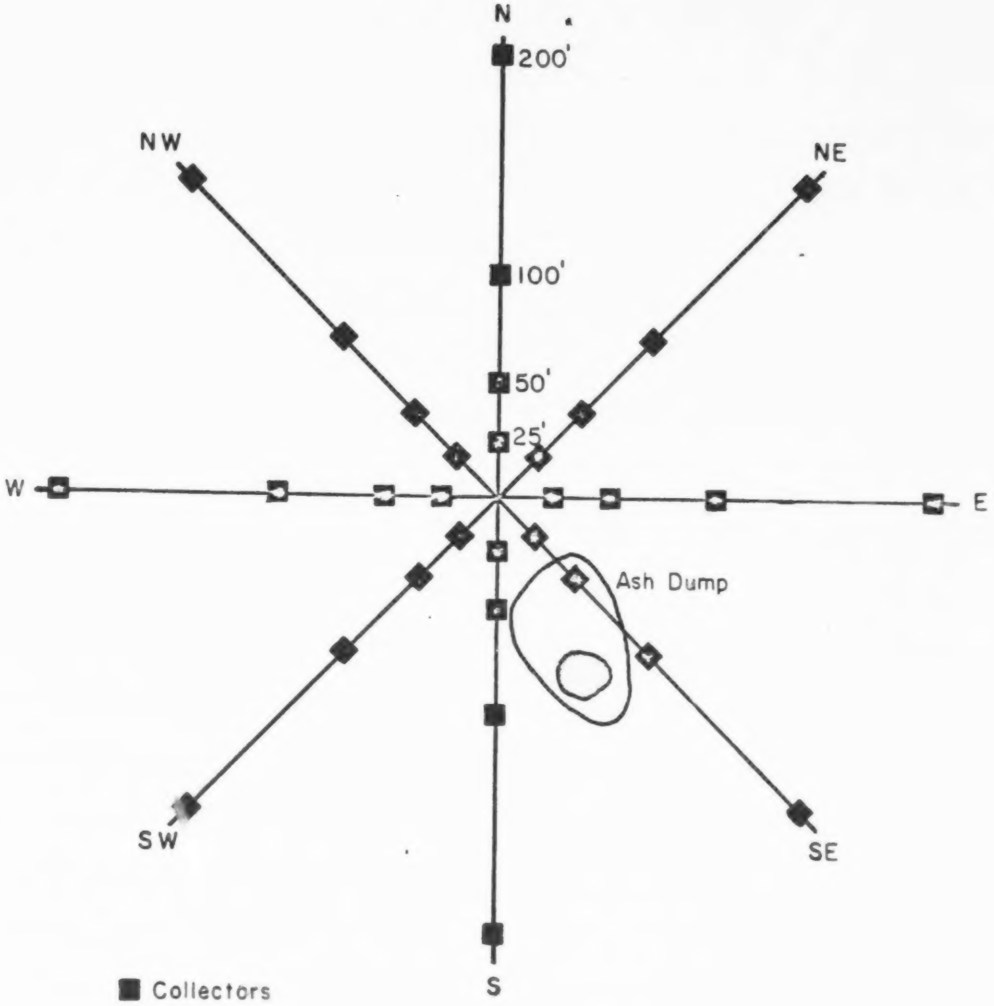

N
200'
NW
NE
100'
50'
25'
W
E
Ash Dump
SW
SE
S
■ Collectors

Figure 5-2 Bottom Collector Array for the Trial Dump of Unsegregated Residue at the Pt. Judith Station.

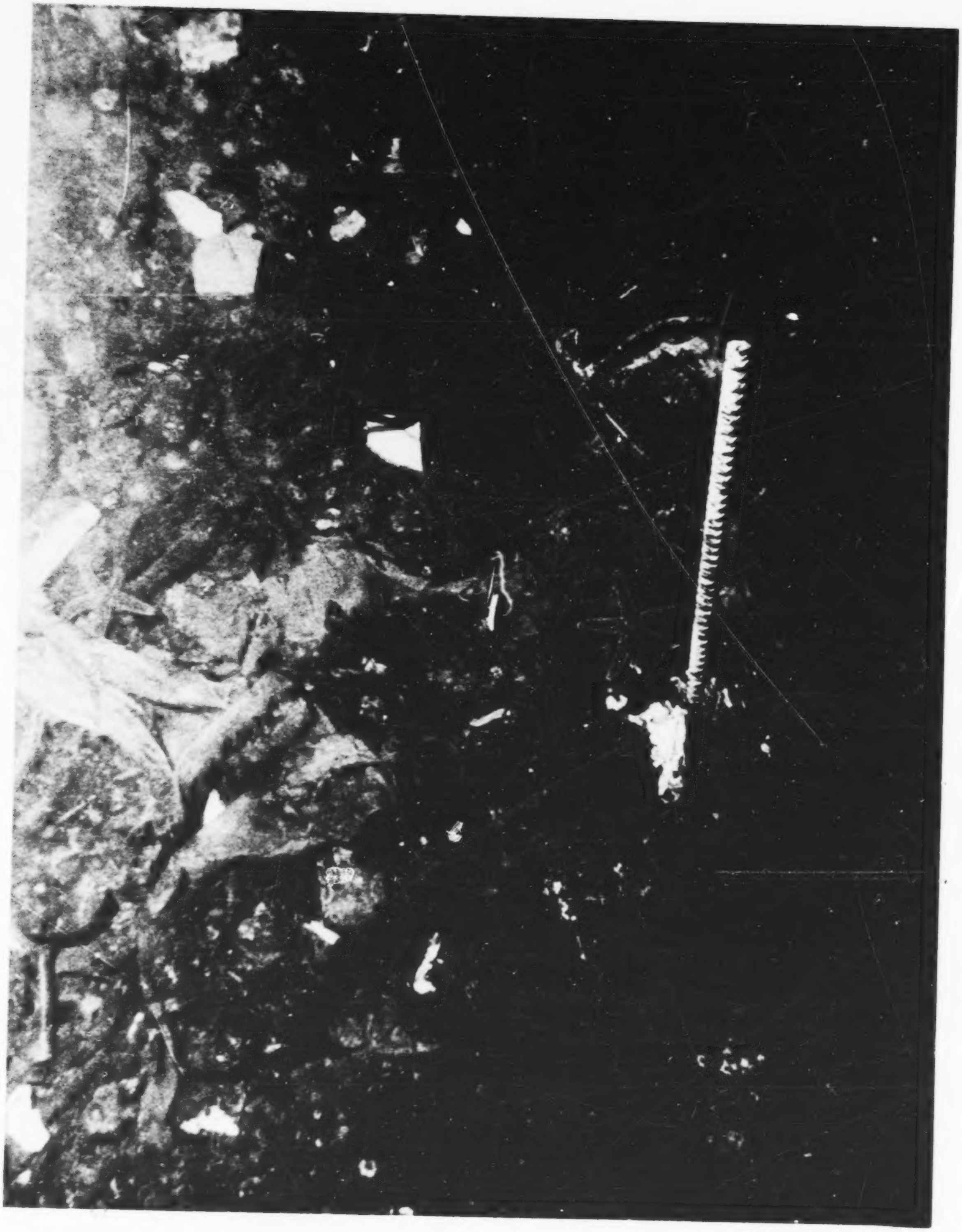


Figure 5-3. The center of the 485 Kg (1000 pound) Dump of Unsegregated Incinerator Residue. Note Unburned Paper.

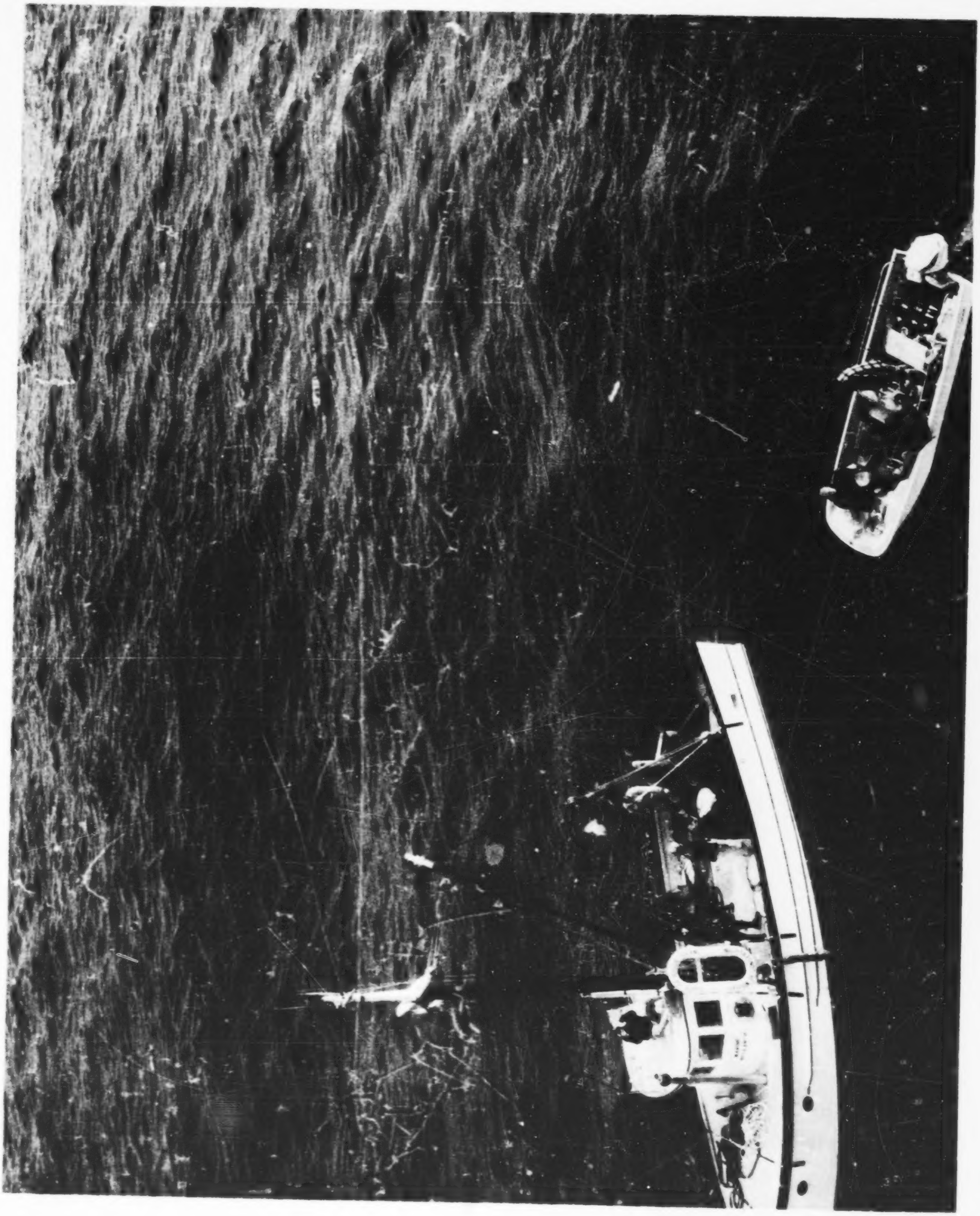


Figure 5-4. The Floating Component of the 485 Kg (1000 pound) Dump of Unsegregated Incinerator Residue in Upper Right of Photograph.

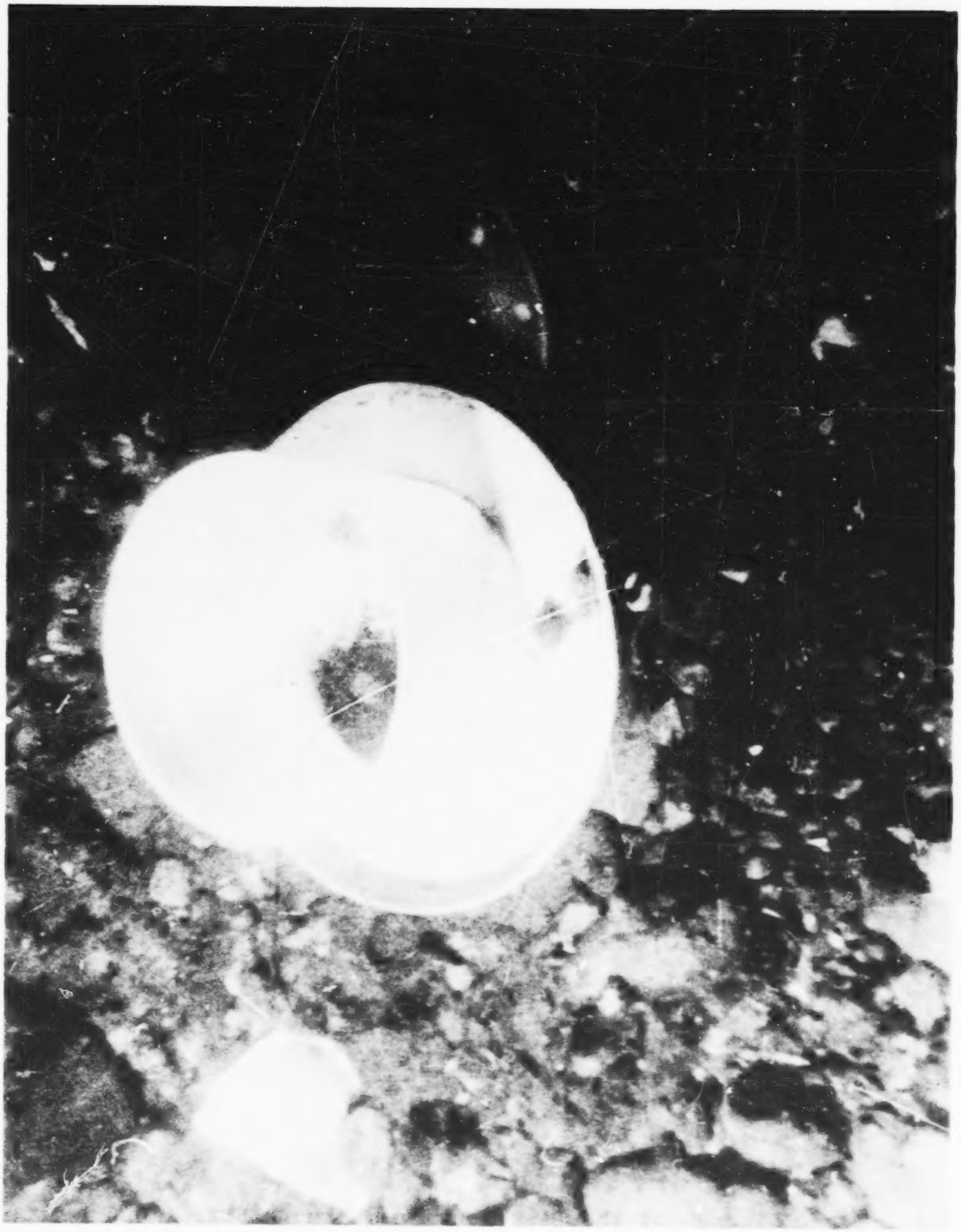


Figure 5-5. Dyed Residue in the 15 M Southeast Collector 9.4 M (29 feet) North of the Center of the Dump One Day After the Dump.

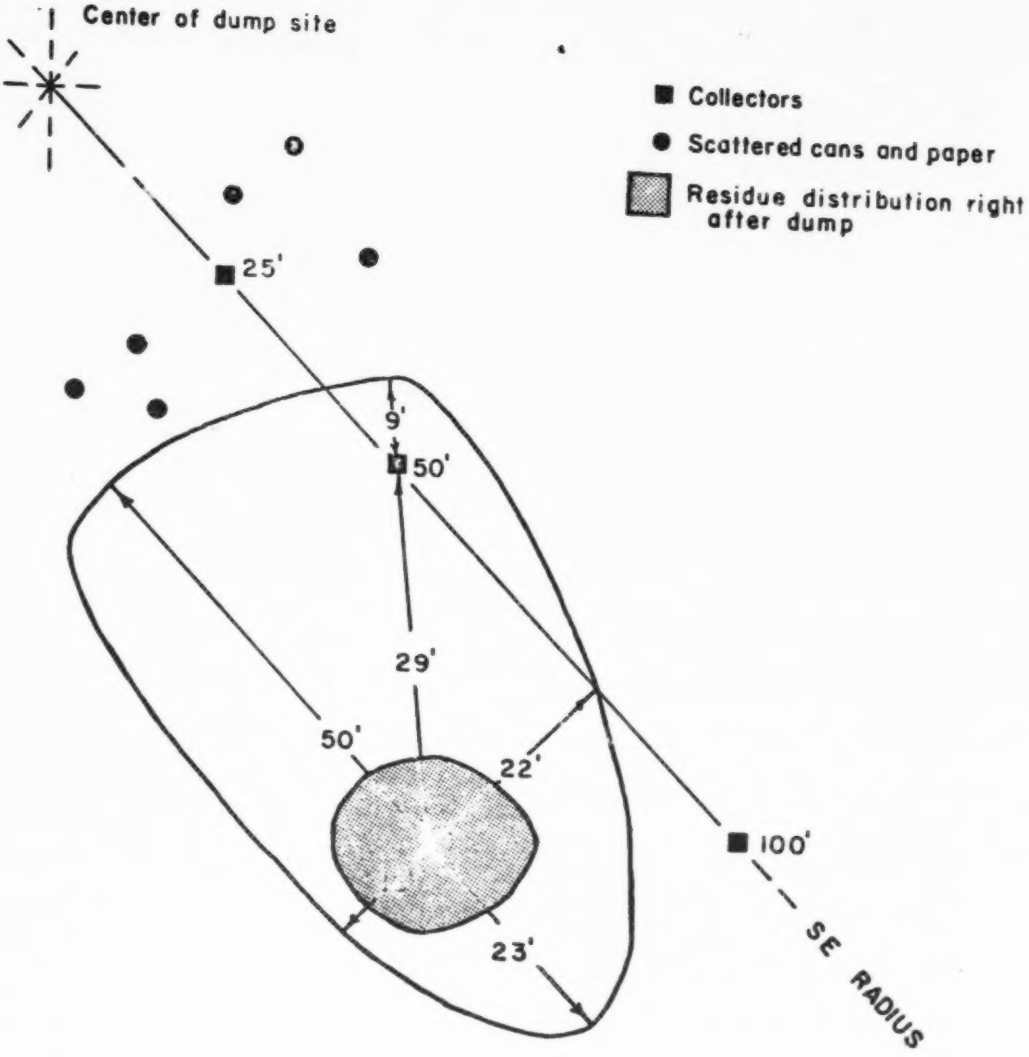

Center of dump site
■ Collectors
● Scattered cans and paper
▨ Residue distribution right after dump
25'
9'
50'
29'
50'
22'
23'
100'
SE RADIUS

Figure 5-6. A Diagram of the Distribution of the 485 Kg (1000 pound) Dump of Unsegregated Incinerator Residue One Week After Dumping.

Discussion

1) Can Movement at Pt. Judith

The results at the 15 M (50 feet) depth at the Pt. Judith Station have been applied to greater depths using classical wave theory (Appendix 5-III). The number of days per year that cans will be set in motion and their net movement at various depths has been roughly estimated.

If drag force is the dominant wave force on a submerged can, the water particle velocity is the pertinent parameter which determines the force. Using classical wave theory the maximum water particle velocity at the bottom for different wave heights, wave periods and depths may be determined.

A 20 minute wave record taken 10/31/67 when divers observed movement of bent and flat cans indicated that for practical applications 15.2 cm/sec was the velocity just necessary to initiate oscillatory movement of bent and flat cans. The maximum particle velocity from this wave record rarely exceeded 30.5 cm/sec. Classical wave theory and these figures were applied to extensive wave data from Hogben and Lumb (1967) in order to estimate what percentage of the time the maximum particle velocity exceeded 15.2 cm/sec and 30.5 cm/sec for different depths.

These percentages are given in Table 5-2 and showed a rapid decrease with depth of the percentage of observations for which the maximum particle velocity would exceed the critical velocities of 15.2 cm/sec and 30.5 cm/sec. For example, the drop was from about 60% or 200 days/year at 15.2 M to about 1% or 3-5 days/year at 91.5 M. Tabulation of observations according to season indicated a much smaller percentage of observations exceeded the

Table 5-2

NUMBER OF OBSERVATIONS IN PERCENT (DAYS/YEAR) FOR WHICH MAXIMUM BOTTOM PARTICLE VELOCITY EXCEEDED A GIVEN AMOUNT FOR DIFFERENT DEPTHS AND DIFFERENT AREAS FOR ALL SEASONS

Area	Particle Velocity Exceeding (cm/sec)	Percent (days/year) Water Depth (M)			
		15.2	30.5	61.0	91.5
(6) 40°-50° N,40°-70°WW	15.2	68(247)	26(130)	4.6(17)	1.3(5)
	30.5	49(177)	22(79)	1.7(6)	0.3(1)
(10) 30°-40° N, 70°-80° W	15.2	64(235)	32(118)	4(14)	1.1(4)
	30.5	43(156)	18(67)	1.3(5)	0.3(1)
(9) 30°-40° N,40°-70° W	15.2	54(197)	9.4(34)	1.7(6)	0.3(1)
	30.5	30(110)	4.2(15)	0.4(2)	0.1(0.6)

critical velocities during the summer season June - August.

On the basis of the net displacement of cans observed by divers in water 15 M deep, an attempt was made to predict the net displacement at different depths. The mechanism by which cans are moved a net distance by waves is probably related to mass transport velocity, the mechanism by which the fluid particles undergo net displacement in a given time. A complication is the fact that tidal current speeds can be the same order of magnitude or greater than bottom mass transport velocity due to wave activity.

Diver observations indicated that a flat can had an average net displacement of 10 M/day. The problem was to estimate what fraction of water particle mass transport velocity the 10 M/day represented. The average water particle displacement in one day at 15.2 M (50 feet) would be about 91.5 M (300 feet) if the maximum bottom particle velocity was 15.2 cm/sec. However, the flat cans moved about 1/10 as far as a water particle. Therefore, neglecting the effect of tidal currents, Table 5-3 gives the displacement distance for flat cans at different depths in the direction of wave propagation.

The neglect of the effect of tidal currents on net displacemetn is serious. Figure 5-7 shows that although the average net displacement of 16 round cans 13 days after dumping was about 2.1 M (7 feet) toward the northwest, 2 cans moved 3.7 M (12 feet) and 4.6 M (15 feet) toward the southeast. A wave mechanism alone predicts a net displacement in the direction of wave propagation, generally toward the northwest. However, the outgoing tidal

Table 5-3

AVERAGE TIME AND DISPLACEMENT OF FLAT CANS IN DIFFERENT DEPTHS BASED ON OBSERVATIONS IN THE NORTHWEST ATLANTIC

Depth (M)	Time (days/year)	Distance (kilometers/year)
15.2	226	2.060
30.5	127	0.910
61.0	13	0.077
91.5	3	0.019

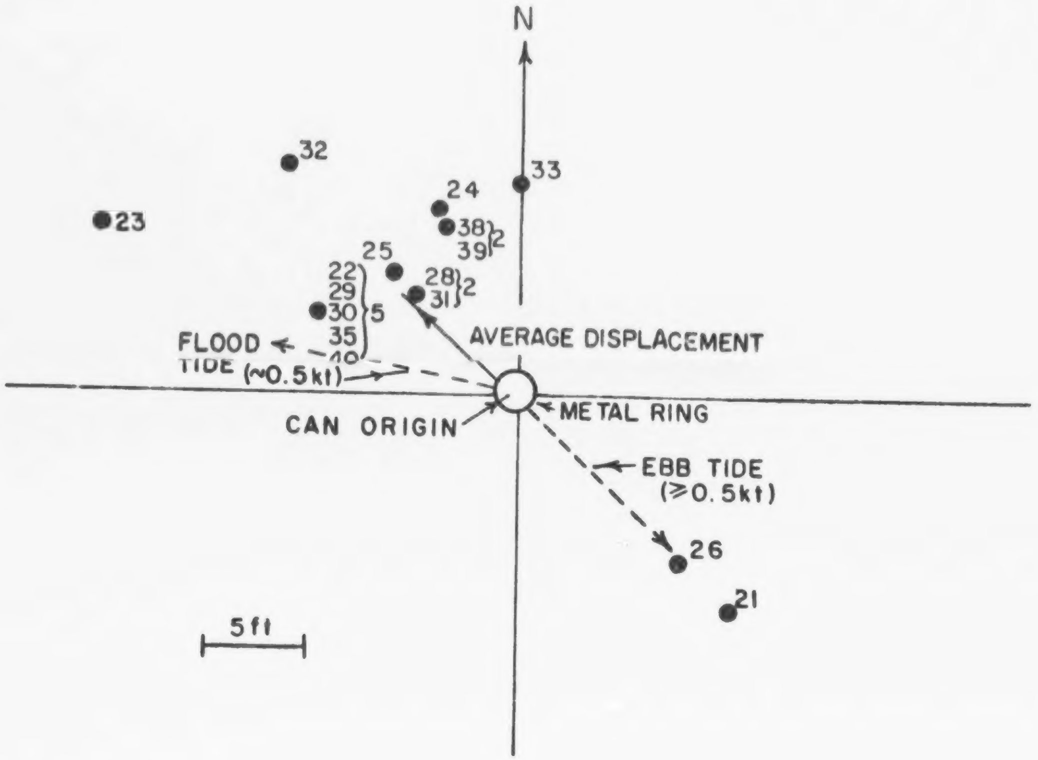

N
33
32
23
24
38
39
2
25
28
31
2
22
29
30
35
40
5
FLOOD
TIDE (~0.5kt)
AVERAGE DISPLACEMENT
CAN ORIGIN
METAL RING
EBB TIDE
(≥0.5kt)
26
21
5ft

Figure 5-7. Round can survey, 8/31/67.

current is toward the southeast. Thus the influence of tidal current has been inferred. **Figure 5-8** shows the net displacement of flat cans over a 19 day interval. This displacement probably took place during a one day storm. Waves from the storm travelled north toward the beach and therefore cans should have been displaced north if their distribution depended on a pure wave mechanism. However, the can distribution had a broad directional band of 135 degrees. This band was probably due to tidal currents.

2) Residue Movement at Pt. Judith

One of the reasons that cans were chosen to model incinerator residue in the dumping experiments was that they form a significant percentage of the residue (about 20%). Cans also may be compared to other components of the residue. Obviously material less dense than cans will move farther along the ocean bottom and objects more dense (such as glass bottles) will move less far (Table 5-4).

The ash component of the residue appears to be less dense than cans. Ash in this context refers to flaky, carbonaceous material such as might be derived from burned paper products. Divers observing about 13.1 Kg (30 pounds) of a residue component less than 12 mm in diameter at the Pt. Judith Station noted ash particles being carried away from the top of the pile by the water current under calm wave conditions. After the 485 Kg (1000 pound) drop of unsegregated residue, divers reported that the ash component had virtually vanished. Thus, apparently this ash component of the residue will be dispersed more widely and rapidly than cans. Unburned cloth and paper which composed

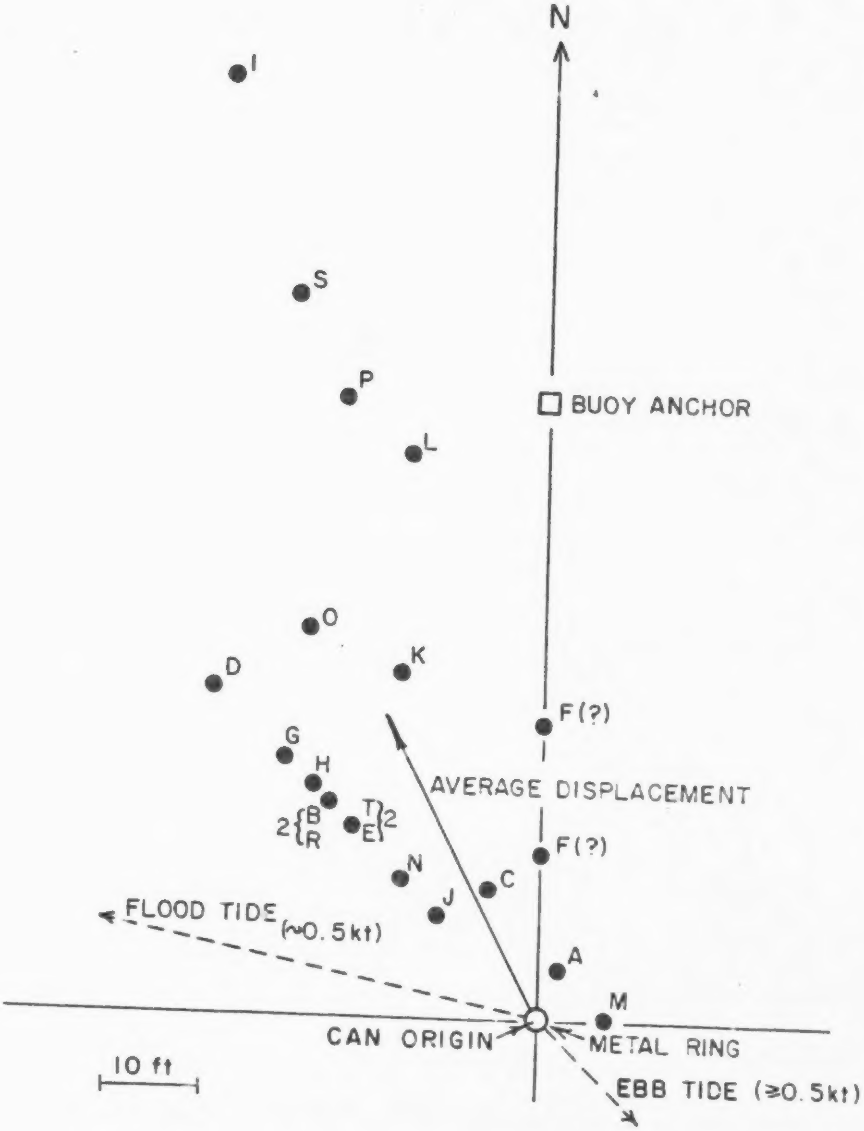

N
I
S
P
BUOY ANCHOR
L
O
K
D
F(?)
G
H
AVERAGE DISPLACEMENT
2{B R
T E}2
F(?)
N
C
J
FLOOD TIDE (~0.5 kt)
A
M
CAN ORIGIN
METAL RING
10 ft
EBB TIDE (≥0.5 kt)

Figure 5-8. Flat Can Survey, 9/19/67.

Table 5-4

FATE OF TOTAL RESIDUE IN OCEAN

	SINK	FLOAT	TOXICITY	COMMENT
Ash (up to 30%)*	Distribute widely to become part of natural sediment	Wash up on shore	Low--but initial turbidity clouds may cause some gill impairment	Thorough incineration would eliminate floating component
Unburned materials (paper, rags, food products, plastics) (up to 20%)	Distribute widely and eventually to be broken down by mechanical agitation & bacterial decay	Wash up on shore		Thorough incineration would eliminate
Cans (up to 20%)	Set in motion during periods of extreme wave activity but in one year to be disintegrated by chemical action	(due to trapped air) May wash up on shore or sink outside of designated dumpsite	Low--but some concentrations of heavy metals	Possible artificial reef phenomenon
Bottles and pieces of glass (up to 20%)	Set in motion during periods of extreme wave activity. Net movement insignificant	(due to trapped air) May wash up on shore or sink outside of designated dumpsite		Possible artificial reef phenomenon
Cinders and fused aggregates (up to 5%)	To become part of natural sediment		Low--but small, highly angular cinders in turbidity clouds may cause some gill impairment	Large cinder aggregates may cause artificial reef phenomenon
Metal Objects (up to 5%)	To become part of natural sediment		Low--but some concentrations of heavy metals	Possible artificial reef phenomenon

* These percent values refer to volume, not weight, and are based on visual estimation. They are apt to vary widely.

a significant percentage of the unsegregated residue was also dispersed rapidly over the ocean bottom. Presumably a large percentage of these two components can be made less of a problem by a more thorough incineration process. Other components of the residue such as glass, metal objects and fused aggregates will move less than cans. Boundaries of the dump of incinerated residue at Pt. Judith were difficult to define on the ocean bottom. However, measurements collected by divers indicated that the dumped material spread from an initial area of 40.6 sq.m. (452 sq.ft.) to 135.0 sq.m. (1500 sq.ft.) in one week's time.

Studies at Cox Ledge Station

Procedures:

The toroidal buoy with a navigation light was again used as an instrument platform and as a station marker. A wind speed and direction recorder and two current speed and direction recorders were used to gather data on station. In addition, a wave recorder was installed at the Pt. Judith Coast Guard Station in 6.1 M of water. Table 5-1 lists the periods during which data was collected and details are given in Appendix 5-I.

A trend surface analysis was not carried out at the Cox Ledge Station. The methodology had been sufficiently worked out at the shallow water site and no large scale dump was anticipated for the deep water site. However, this approach is considered useful for empirical study of anticipated large scale dumping experiments.

Cans and bottles of various shapes and sizes in four separate dumps were used to simulate incinerator residue. Four surveys of these objects in 54 M of water were conducted during the summer and fall at the Cox Ledge Station. A two man submarine, containing a pilot and an observer was used to observe and photograph the dumps. Orientation on the bottom was maintained by a grid type search pattern, by underwater markers, and by communications from the surface on the position of the submarine tether relative to station buoys (Appendix 5-IV).

The procedures for the first survey during June 17-19 were to become familiar with using a search pattern on the bottom, and to observe the four dumps on the bottom. The procedures and objectives of the 3 later surveys were to map the location of the dumps and underwater markers, to take photographs of the dumps and to determine if the objects had moved and to what extent they had moved. Before the fourth survey (October 21 to November 1, 1968) a southeast storm with wind gusts to 97 kilometers/hr occurred on September 11. This storm should have created waves large enough to affect the bottom. In addition, the storm cleared the station of all marker buoys, posing some difficulty in relocating the station.

Results:

Current directions at 54 M (177 feet) were restricted mostly to northeast and southwest directions (Figure 5-9). Current directions were related to bottom contours (Figure 5-10). Apparently the deep area (in contrast to surrounding areas) was caused, or at least was maintained, by bottom currents. Maximum

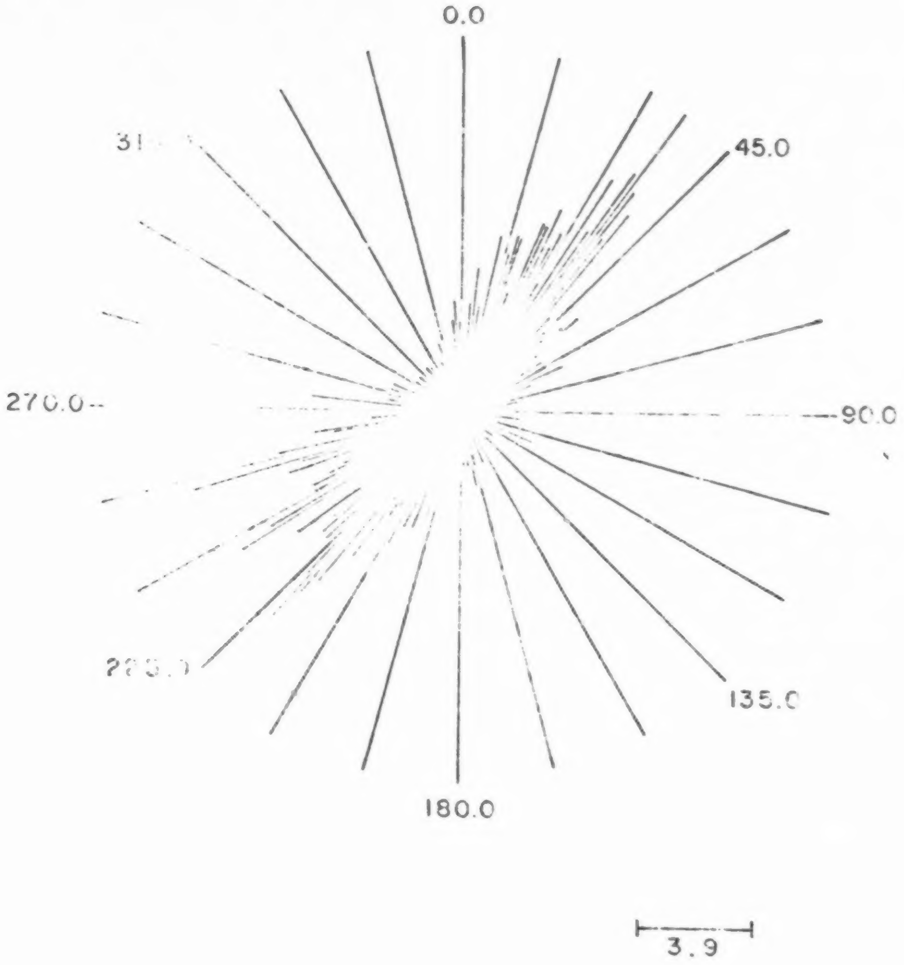


Figure 5-9. A Polar Coordinate Histogram of Current Direction at 54 M (177 feet) depth at the Cox Ledge Station Between May 31 and July 10, 1968.

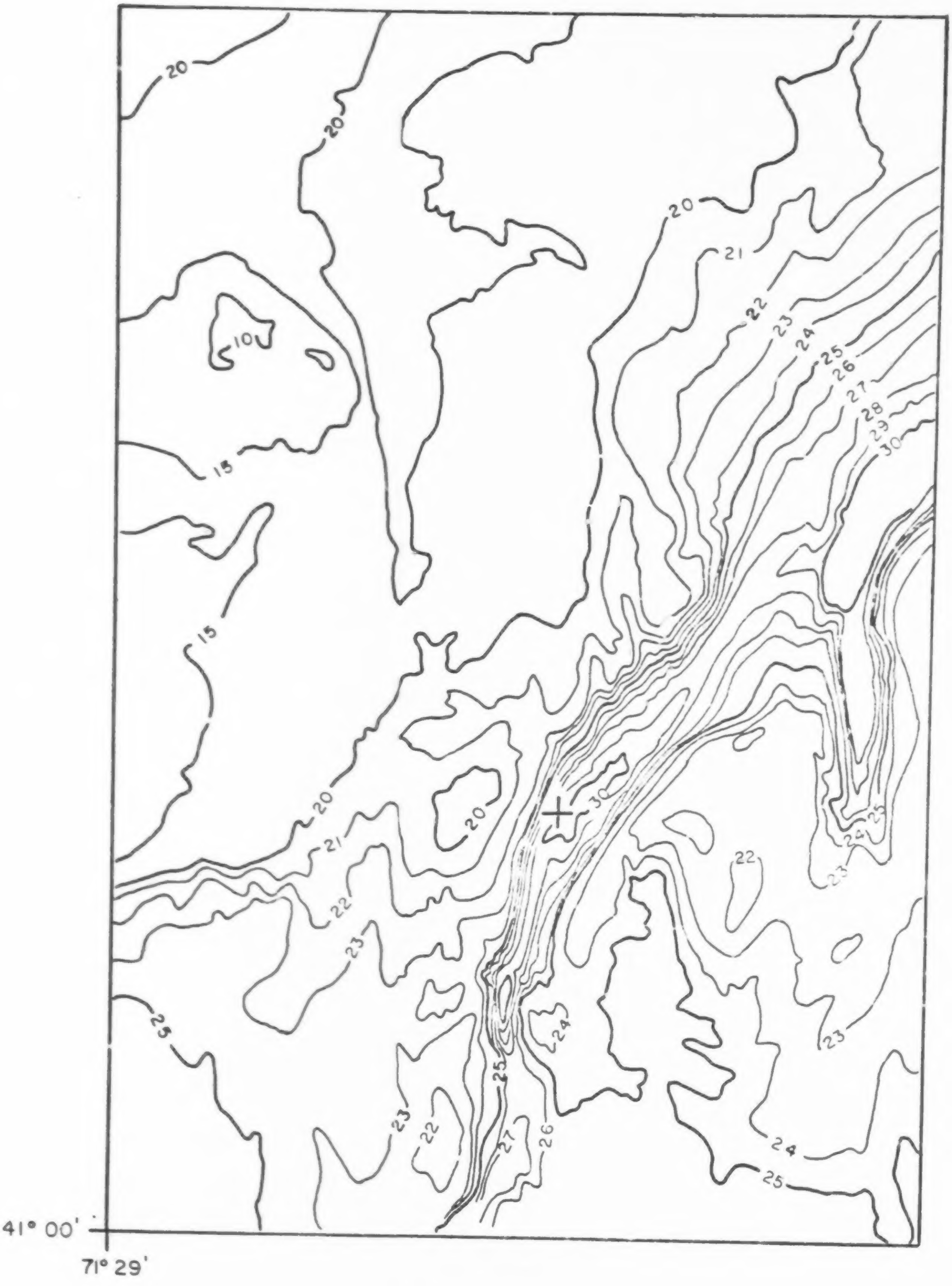

20
20
20
21
22
23
24
25
26
27
28
29
30
10
15
15
20
21
20
30
22
22
23
25
24
25
23
22
27
26
24
25
23
24
25
23
41° 00'
71° 29'

Figure 5-10: Bottom Contour Chart of the Area East of Block Island. The Cross marks the location of the experimental dumpsite. (From C and GS chart number 0808N-51)

current velocities on the bottom were 20 cm/sec, average velocities were 5 cm/sec.

The appearance of the bottom at the deep water site was that of a fairly smooth silt clay which rose up in clouds around the submarine during reverse movements. Animal activity was indicated by many small marks, mounds and burrows on the surface of the bottom. Five species of animals were observed during the first survey, 12 during the second, 10 during the third and 15 during the fourth (Table5-5). During the last survey, when a fairly substantial current occurred, small shrimp on the bottom were observed to be aligned with the current, and hake (Urophycis chuss) were observed to be facing into the current.

No movement of objects was detected in the first 3 surveys (Appendix 5-IV) .However, before the fourth survey, weather conditions became more violent. A southeast storm with wind gusts to 97 kilometers/hr (60 mph) occurred September 11, 1968 and could have produced waves large enough to affect the bottom.

During this last survey ripple marks with their long axis in an east-west direction and a substantial bottom current to the northeast were encountered for the first time. Most of the cans appeared to have remained on the basket (Figure 5-11).However, several had been shifted off in a southwest direction. The maximum distance recorded was about 15 M for a 2.9 l (1/2 gallon) round can (Figure 5-12).The bottles had also been disturbed. The maximum observed distance moved, however, was only 2 M in a southwest direction.

Table 5-5. Numbers of species and individuals observed during submarine surveys at one location 14.4 kilometers (9 miles) southeast of Block Island on a silt-clay bottom during the summer and fall of 1968.

	Red Hake (Urophycis chuss)	Scup (Stenotomus chrysops)	Eelpout (Macrozoarces americanus)	Yellow-tail flounder (Limanda ferruginea)	Winter Flounder (Pseudopleuronectes americanus)	Goosefish (Lophius americanus)	Cod (Gadus morhua)	Sculpin (Myoxocephalus sp.)	Unidentified hake-like fish	Juvenile fish (Probably Hake)	Skate (Raja sp.)	Dogfish (Squalus acanthias)	Starfish (Asterias forbesi) (Hippasteria phrygiana)	Johna crab (Cancer borialis)	Lobster (Homarus americanus)	Small shrimp-like crustacea	Sea Scallop (Placopecten magellanicus)	Squid (Loligo pealii)
First Survey: visibility: 1.5M time on the bottom: 7 hr.			*several	**few		few							several				few	
Second Survey: visibility: 3M time on the bottom: 7 hr.	several	few	several		several	few	few						several	several	few	***many	several	
Third Survey: visibility: 3M time on the bottom: 7 3/4 hr	several		several		several	few				several			several	several	few	many	several	
Fourth Survey: visibility: 3M time on the bottom: 4 1/2 hr	several	few	several		several	few		few	several	few	few	few	several	several	few	many	several	few

*several: 20-500 **few: less than 20 ***many: over 500.

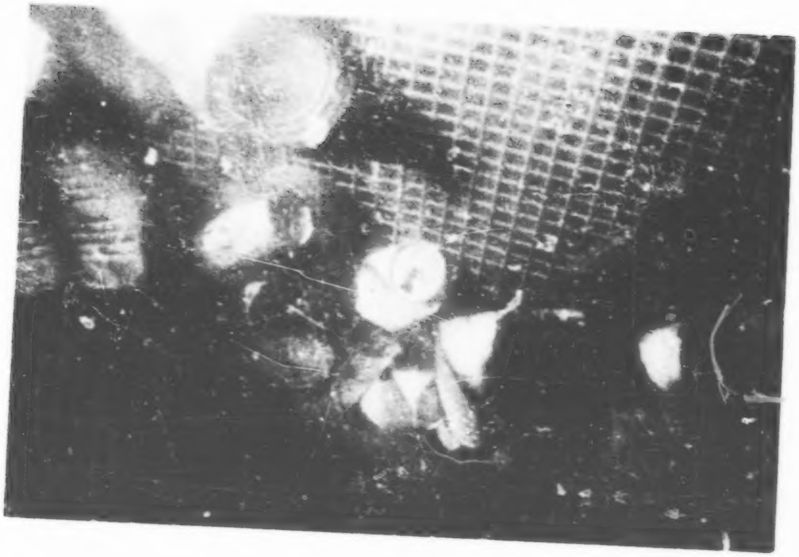


Figure 5-11. Fourth Submarine Survey. A view of the east dump showing cans which have been cleared to form a row across the center of the basket.

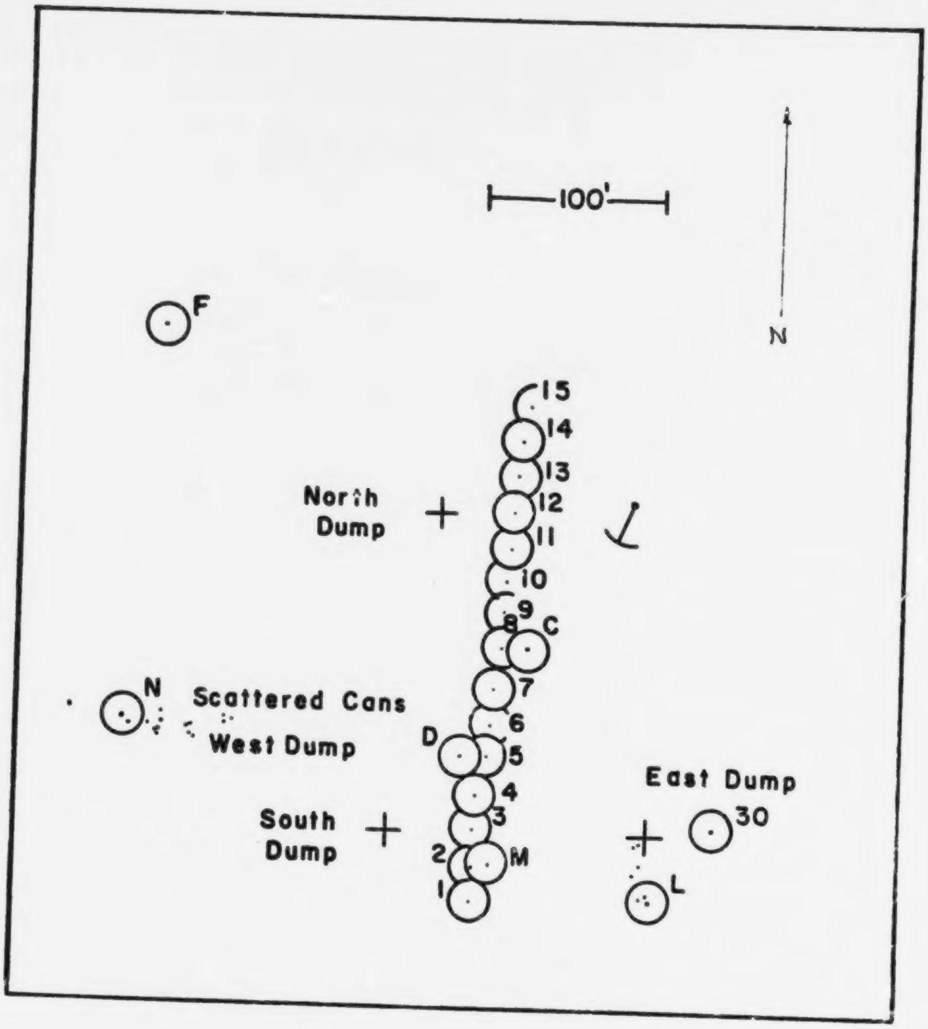

100'
N
F
15
14
13
12
11
10
9
8
C
7
6
5
4
3
2
1
M
D
North Dump
Scattered Cans
N
West Dump
South Dump
East Dump
30
L

Figure 5-12. Chart of the relative positions of objects on the bottom at the experimental site at the Cox Ledge Station during the fourth submarine survey. Letters and numbers refer to underwater markers. The positions of the dumps are indicated by crosses. The anchor is from the former center buoy.

Discussion

Statistics on wave height for the mid-Atlantic indicate that wave-caused orbital velocities between 15.2 and 30.5 cm/sec (velocities sufficient to move cans according to Pt. Judith study in 1967) at a 61.0 M depth are reached from 1.5% to 4.9% of the time during September to November (Table 5-6). The movement observed on the bottom during the fourth survey was probably due to the storm of September 11, 1968. Winds as strong or stronger occurred on November 12, and November 20. On this basis, it is suggested that from September to November 1968 conditions severe enough to move cans could have occurred 3% of the time. This figure compares favorably with the above figure derived from the analysis of wave statistics.

At the Wickford laboratory, 28 incinerated cans were placed in a plastic, 1 mm mesh bag and suspended off the dock into the sea water in November 1967. Dry weights of these cans were measured in December, March, June and August. Weights of these cans did not tend to decrease. On the contrary, many increased in weight. However, by August only 4 cans were still identifiable as individuals and the rest had disintegrated into flat, crumbly pieces of scale. A second batch of 24 incinerated cans with a total weight of 2085 gm was placed off the dock December 1967. By December 1968 the total weight of the cans was 2683 gm (Figure 5-13). However, only 9 cans would be identified as individuals and very little can shape remained in these (Figure 5-14). On this basis it seems safe to predict that the life of an incinerated can in sea water would be no longer than 1 year.

Table 5-6

PERCENT OF TIME AND DAYS THAT CAN MOVEMENT OCCURRED AT A 61 M (200 FOOT) DEPTH AS A FUNCTION OF SURFACE WAVE ACTIVITY

(Hogben and Lumb, 1967)

Mid-Atlantic Area (30°-40°N, 40°-70°W)	Wave Caused Orbital Velocities Sufficient to Move Cans	61 M Depth	
		% of time	Days/year
September to November	15.2 cm/sec	4.9	4
	30.5 cm/sec	1.5	1.5
Whole Year	15.2 cm/sec	4	15
	30.5 cm/sec	1.3	5

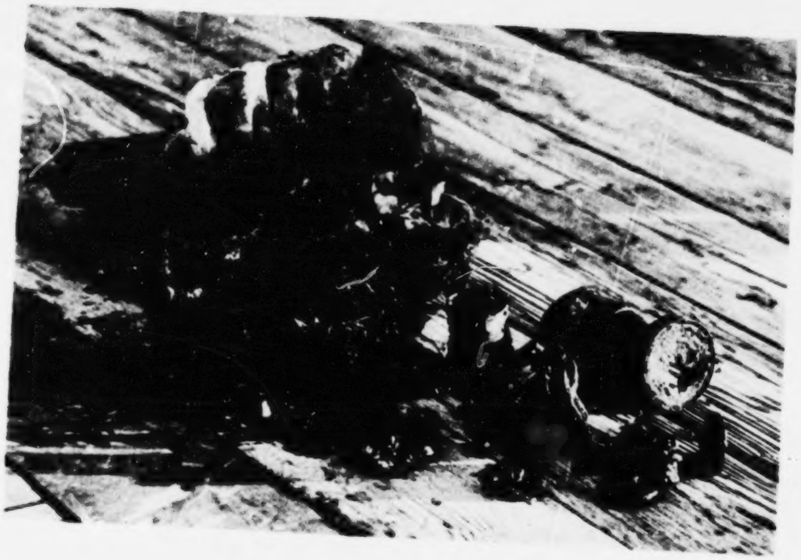


Figure 5-13. Remains of 24 incinerated cans after one year in sea water.

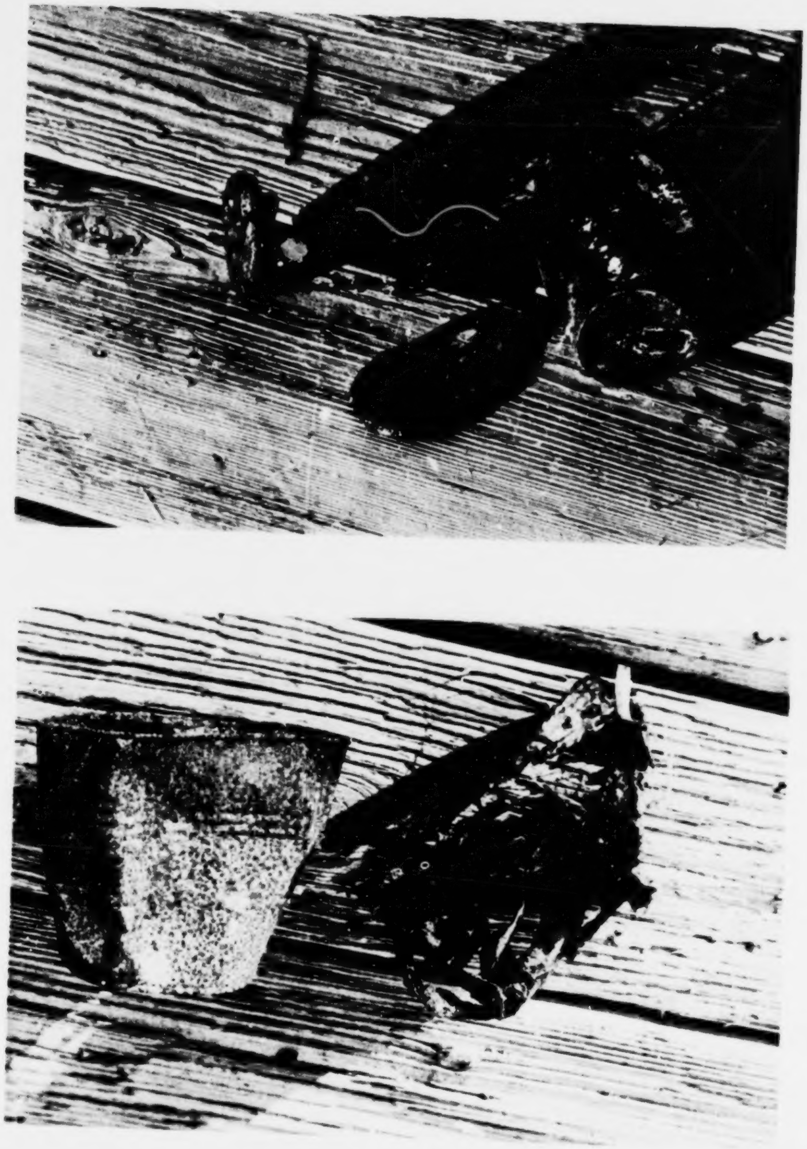


Figure 5-14. Two examples of untreated incinerated cans next to ones of the same size which had been held in sea water for 1 year.

The maximum distance that a round, 1.9 l (half gallon) can was observed (from the submarine) to have moved was about 15 M. Others could have moved farther and not been observed. However, most of the cans appeared not to have moved significantly from their point of origin. If the figure from wave statistics is reliable, and it appears to be, waves severe enough to move cans occur 5-15 days out of a year (Table 5-6). Tentatively, under extreme conditions, round, 1.9 l (half gallon) cans could then move 229 M (750 feet) per year (15 days times 15 M [50 feet]) at a 61 M (200 feet) depth. However, according to the can disintegration experiments, by the time this maximum distance had been reached the cans should be reduced to scale. In an actual 3.43 square kilometer (square mile) dumping area, this 229 M (750 foot) distance becomes insignificant.

Near the shore, waves propagate nearly perpendicular and tidal currents nearly parallel the shore line. The waves will tend to move material on the bottom toward the shore, and the tidal currents will tend to scatter the material parallel to the shore. The relative magnitudes of the on-shore and along-shore movement under given conditions is not known. The Point Judith can experiments suggest that for surface tidal currents up to 52 cm/sec and a depth of 15.2 M the wave effect may be somewhat more important than the current effect.

Both wave and current effects should decrease in deeper water. If the tidal currents are the same at the bottom, one would expect that the current effect would become relatively more important than these wave effects in deeper water. This is due to the fact that the net water particle velocity (mass transport velocity) decreases with depth much faster than orbital particle velocity. Thus, in deeper water the orbital velocity could still be sufficient to start a can rolling back and forth, but the tendency to a net movement would be much reduced. Tidal currents also decrease with depth. The average bottom current velocity at the Pt. Judith Station was 21 cm/sec as opposed to the average velocity of 5 cm/sec at the Cox Ledge Station. The distribution of objects at the Cox Ledge Station indicated that the current effect determines the direction of distribution but the current effect cannot operate without the wave effects since currents are not able to move cans in the absence of waves.

In conclusion, cans placed at the experimental dump site at the Cox Ledge Station were observed during the fourth submarine survey to have moved several meters in a southwest direction. This movement was probably the result of storm waves surging the cans up into southwest moving water currents. Currents measured 2 M (6 feet) off the bottom were at times sufficient to move cans in southwest or northeast directions. In a one-year period of time, wave statistics indicate that cans would probably be moved several tenths of a kilometer at a 61 M depth and distributed according to predominating currents in northeast and southwest directions. However, in a one-year period of time the cans would probably be reduced to small soft pieces of scale. Wave activity, agitating the cans, would hasten this disintegration process. After 5 months during the fourth survey, the painted unincinerated cans were observed to have large rust holes. The results of this study suggest that in waters of 61 M depth or greater, residue movement on the bottom would become progressively less significant.

Recommendations for Selecting an Off-Shore Dumpsite for Incinerator Residue.

1. Offshore areas of similar depths have individual characteristics. For this reason selected areas should be surveyed prior to any dumping operations. The survey should include the following:

a) Sediments and bottom contours. These area characteristics indicate the strength of natural forces which are acting on the bottom. An area of deposition would be indicated by a fairly level silt-clay bottom. An area of activity would be indicated by rapidly changing depths with rocks or clean sand and gravel formed into ripples.

b) The biology. The flora and fauna must be surveyed for two reasons. (1) A preliminary survey would indicate the presence or absence of economically important species. (2) Secondly, surveys before and during dumping operations would indicate changes in abundance. It is not altogether unlikely that incinerator residue would attract sport fishes in the same manner as artificial reefs. Fishes and crustacea were apparently attracted to the experimental dumps at the Cox Ledge Station.

c) Depth, bottom currents and wave activity. These parameters will determine the degree of movement activity at a dumping site. This fact was demonstrated at both the shallow water and the deep water sites. The shallow water site tidal currents were strong and while the wave activity was much less than off-shore wave activity, the shallow depth allowed much of this activity to reach the bottom. Consequently, residue was distributed widely. At the deeper water site bottom currents were less strong and even the strong wave activity was largely filtered out by the increased depth. Can movement was slight. Also, in the shallow water, objects were observed to be moved in the direction of wave propagation (toward the shore) wheras, in the deeper water, objects were observed, to be distributed in the direction of predominating currents.

2. An incinerator residue dump site should probably be at least 61 M deep and the area at this depth should be at least 1 sq. mi. to contain the residues after one year of movement.

Bottom currents during all of our observations were insufficient to move cans by themselves. However, extreme wave activity will reach the bottom at this depth and material will be shifted according to the direction of bottom currents. Therefore the site area must be large enough to contain this movement. If the materials migrate into shallower waters, movement will probably be exponentially accelerated. During a one year period a percentage of the residue will decay and become less subject to movement. One other consideration is that repeated dumping episodes over the years will eventually shoal an area.

3. The residues should be thoroughly incinerated and crushed. Otherwise, some unincinerated materials have a low density. Some are apt to float. Those unincinerated materials that reach the

bottom will move faster and farther than cans. Crushing the cans and breaking bottles reduces their tendency to float or to move under extreme oceanic conditions.

Summary Conclusions

A. Can Movement at the Pt. Judith Station, 1967.

The following conclusions are based on direct observations by SCUBA divers of the movement of 360 cm^3 cans along the bottom in water 15 M (50 feet) deep at the Pt. Judith Station.

1) Average net displacements of up to 0.3 M/day in the general direction toward the shore have been measured.

2) Cans have been observed moving back and forth when the wave heights were large (1.22 M) and the tidal currents were small (15.5 cm/sec).

3) Cans have been observed not to move when the wave heights were small (0.31 M) and the tidal currents were large (38.7 cm/sec).

4) Bent or flattened cans are less easily set into motion and do not move as far as similar cans of undistorted shape.

5) For cans of the same shape, those with the largest specific gravity are least easily moved.

6) Can motion occurred in general during periods of extreme wave activity due to storms.

B. The conclusions which follow are based on the observations in water 15 M (50 feet) deep at Pt. Judith Station, on published wave data for the northwest Atlantic, and on classical wave theory.

1) The can movement observed in a depth of 15 M (50 feet) will occur to some degree in all water depths over the continental shelf.

2) Can movement is generally expected to decrease quite rapidly with depth. For example, at a depth of 91.5 M (300 feet), cans might be expected to move during only a few days (up to 5) a total distance of only a few feet (up to 15 M) during an average year. The displacement in water 61 M (200 feet) deep may be 4 times as great, and the displacement for a depth of 30.5 M (100 feet) may be 50 times as great.

3) In the absence of tidal or other currents the net can movement will be in the direction of wave propagation.

C. Observations on Incinerator Residue Movement at Pt. Judith, 1967.

1) The less dense ash component of the total residue will be more rapidly dispersed than the can component and glass; metal objects and fused aggregates will be less widely dispersed than cans.

2) At a 15 M (50 feet) water depth, in one week's time a 485 Kg (1000 pound) residue dump became dispersed over an area 3.3 times larger than the area covered immediately after dumping.

D. Observations on Can Movement at the Cox Ledge Station, 1968.

1) No can movement was observed during 3 submarine surveys during the summer at a water depth of 54 M (177 feet).

2) During the fall submarine survey, after a substantial storm, a few cans had moved several meters. However, most cans remained at their point of origin.

3) The cans which moved were distributed in the direction of predominating bottom currents.

4) According to wave statistics for the area and the depth

of water, cans could move several tenths of a kilometer during a one-year period.

5) In a one-year period of exposure to sea water, cans disintegrate into soft scales of rust.

6) It is recommended on the basis of this study that an incinerator residue dump site be in water at least 61 M (200 feet) deep and encompass an area **one sq. mi.** to provide for one year of movement.

REFERENCES

Hogben, N. and F. E. Lumb (1967). Ocean Wave Statistics, D. R. Hillman and Sons, Ltd., London, 263 pp.

Appendix 5-I -- Station Buoy Configurations

1. Pt. Judith, 1967

One state and two federal agencies must grant approval before a special purpose buoy can be placed in inland waters. The Rhode Island Department of Natural Resources Division of Harbors and Rivers has first authority to determine whether or not the rights of the public will be jeopardized. The Coast Guard must be informed so that they may publish the information in their Notice to Mariners. Finally, the Army Corps of Engineers must be informed so that they may ascertain whether or not the buoy is a hazard to navigation.

After final approval had been granted, the buoy and its instruments were set at the site during the first week of August 1967. A foam-filled fiberglass-covered surface buoy (2.4 M) was used as an instrument platform and a position marker. The buoy was supplied with a 3.1 M tripod tower and two instrument shelves. A flashing navigation light was placed on the upper shelf and a wind speed and direction recorder (Geodyne Model 998) was placed on the lower shelf (not until 10/17/67). The buoy was moored with 23 M of 1.3 cm galvanized chain to a cement block (0.9 M x 1.2 M x 0.2 M). An additional 23 M of 1.3 cm galvanized chain was attached to this block and led to a second circular cement block (0.3 M height and 0.6 M in diameter) which served to anchor the instrument package. The instrument package was attached to its anchor with 2 M of 1.59 cm (5/8") polypropylene line and this line was attached to the bottom current meter (Geodyne Model 102). Directly above the current meter the bottom temperature recorder (Geodyne Recorder) was attached. This recorder was attached to the top current meter with 4.8 M (15'8") of 1.59 cm (5/8") polypropylene line for a total of 9.3 M above the bottom. The top temperature recorder was attached directly above the top current meter and to a submerged buoyancy buoy (.45 M diameter). Two plastic seine floats were added to this buoy to keep the instruments vertical. From these buoys a small line was attached to a surface position marker.

A storm caused the toroidal buoy anchor to shift some 180 M west-northwest so an additional 485 Kg anchor was attached 24 M from the old anchor with 1.8 cm (1/2") wire. The wave height recorder holder (6.4 M galvanized T-pipe fitting soldered to a half round of brass) was attached to this new anchor by 12 M of 0.95 cm (3/8") polypropylene and suspended by a submerged buoy(0.45 M diameter) with a small line leading to a surface position marker (8/31/67).

In the first data collecting period the two current meters and the two temperature recorders were launched 11:45 (DST) August 8, 1967, and recovered 12:00 (DST) September 8, 1967. Both temperature recorders had traces. Bottom temperatures tended to lag behind surface temperatures by about 5 days but followed the same pattern as surface temperatures. Generally, surface water was 0.5 to 1.0°C higher on the high tides than on the low tides. Bottom temperature reflected this pattern to a lesser degree. The range of temperature for the surface was 16 to 19°C and for the bottom 14.5 to 19°C.

The bottom current meter failed to record any data. The top current meter had a damaged rotor after August 31, but recorded direction for the entire 31 days. Cursory examination indicated rotary tidal currents moving in toward 310 degrees and out 90 to 100 degrees with speeds up to almost 51.6 cm/sec (1 knot) and averaging 26 cm/sec (0.5 knot). Strong winds tended to prolong or diminish tidal periods.

In the second data collection period,two current meters were placed 9/8/67 12:15 (DST) and recovered 11/8/67 11:35 (EST). The two temperature recorders were placed 9/19/67 and recovered 11/8/67. The bottom temperature recorder jammed and failed to record. The top recorder indicated a high temperature of 15°C at the beginning of the period and a low temperature of 11°C at the end of the period. Wave height records were made intermittently over the two month period. Maximum wave height recorded was approximately 1.5 M. Current meter records were not significantly different from the first data collection period. Examination of the strip chart indicated that the top meter had, on the average, an outgoing total current of 21 to 26 cm/sec; while incoming tidal current averaged 31 to 36 cm/sec. On October 21, fouling by the pink hearted hydroid (Tubularia crocea) started to reduce the efficiency of the rotors and by October 29 the rotor was completely stopped. The vane, however, continued to operate for the entire period. The strip chart for the bottom current meter showed incoming tides from 90 degrees and out-going tides at 300 degrees; both current velocities were about 21 cm/sec. Maximum currents on the bottom were about 31 cm/sec. Considerable tilting and fouling on the bottom meter reduced its efficiency for the second month of the data collection period.

2. Cox Ledge, 1968

Since the deep water station was in international waters, only the Coast Guard had to be informed.

The toroidal buoy was placed on station on June 5, 1968. The buoy was supplied with a 3 M tripod tower and two instrument shelves. A flashing navigation light was placed on the upper shelf and a wind speed and direction recorder was placed on the lower shelf. The toroidal buoy was moored with 106 M of 1.59 cm (5/8") nylon and 23 M of 1.3 cm (1/2") chain connected to a 190 l (50 gallon) drum filled with cement to a weight of 629 Kg.

This mooring proved inadequate and the toroid left its station August 16, 1968. On August 21, 1968 the toroid came ashore on the west side of Block Island. The buoy and instruments were recovered August 23, 1968. However, private parties had started to salvage the toroid. Damage to the wind recorder and the navigation light was largely due to their efforts and this damage prevented the return of these instruments to the station with the buoy, September 14, 1968. This time the toroid was anchored with 122 M of 0.95 cm (3/8") chain to a 454 Kg cement slab. On October 15, 1968, the Block Island Coast Guard removed the buoy to Block Island because the navigation light was not in place. However, they replaced the buoy on station October 16, 1968 at our request.

Current Meter Moorings

During the first data collection period, two Geodyne (Richardson type) Sylvanius rotor current meters were placed on station May 31, 1968, and recovered July 10, 1968 (Figure 5-15). Two recovery lines were attached to the instrument array and the auxilliary buoy was missing when the instruments were recovered (Figure 5-16).

During the second data collection period two meters were placed on station July 18, 1968, in a slightly different configuration (Figure 5-17.) The buoy marking this position was missing August 14, 1968. On September 18, 1968, the meters were recovered in good condition by a bottom trawling fisherman in 31 M of water SSE of Shinecock Inlet on the south side of Long Island some 65 kilometers from where they were set. Both buoys and the anchor were missing. In addition, the rotors of both instruments were damaged.

Surface currents appeared to have a clockwise rotary pattern which did not appear to be directly related to the tides. The current direction of one low tide period may be 130 degrees different from the next low tide period or the current direction during high tide may be the same as at low tide (Table 5-7). Nevertheless, during an average 24 hour period, current direction changed from a northerly direction clockwise until it was again northerly.

The predominating directions of the surface currents were southwest to northwest (Figure 5-18). Data collected during the second period while the meters were drifting on the surface have a

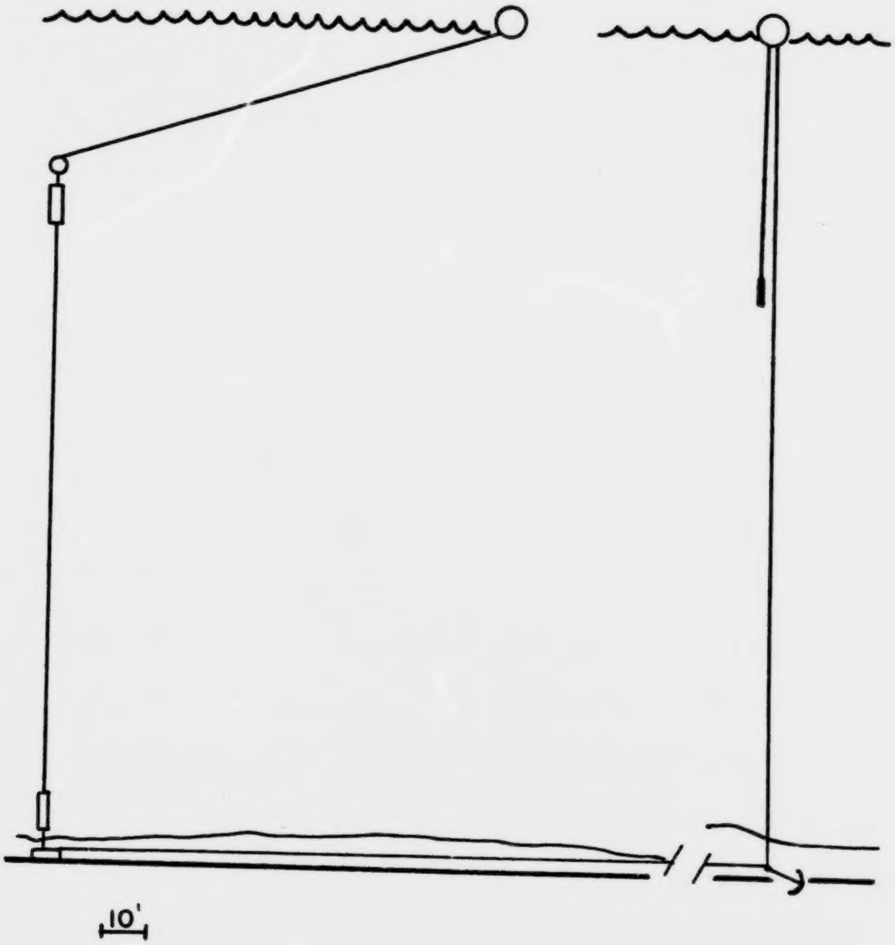


Figure 5-15. Diagrammatic appearance of the current meter instrument array on station, May 29, 1968.

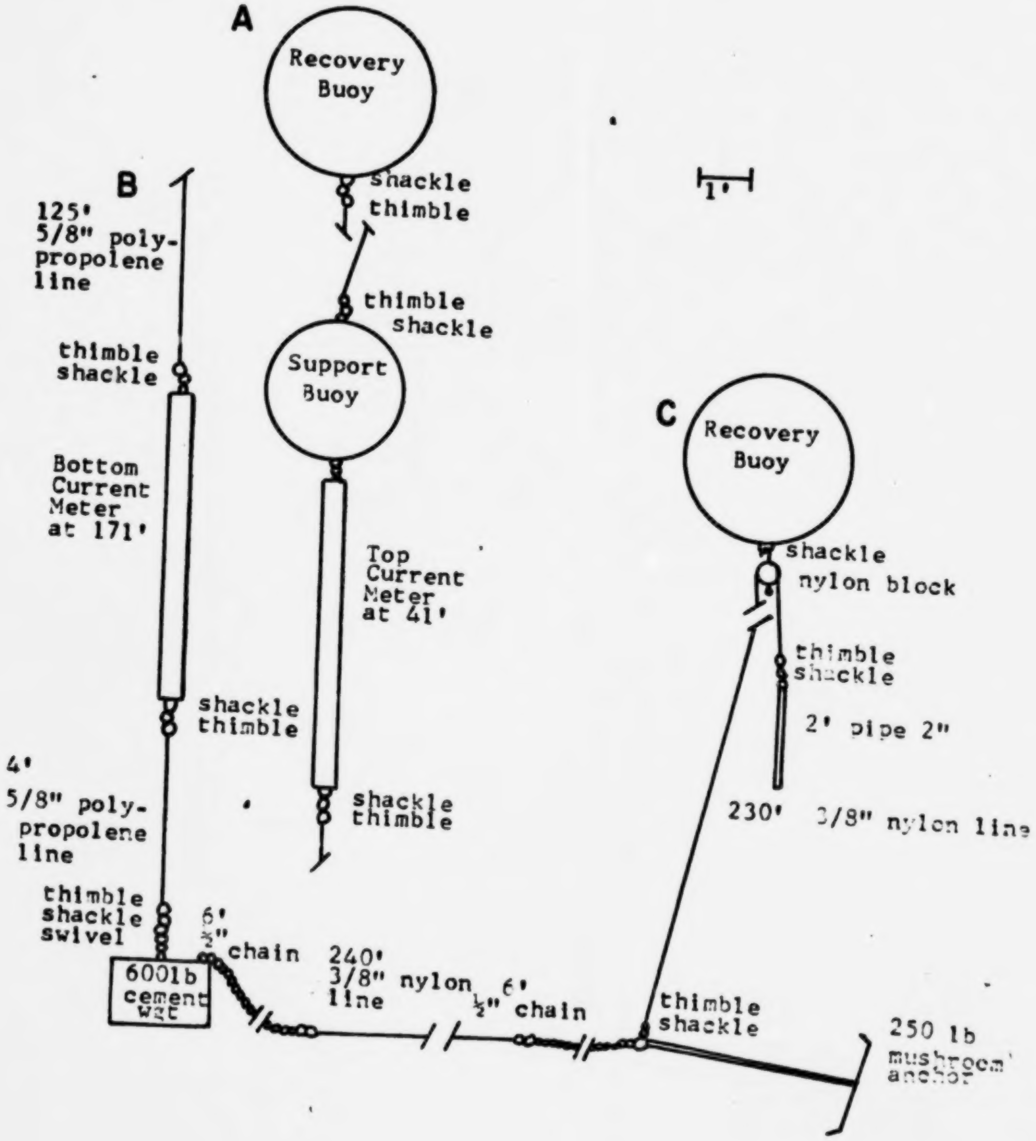

A
Recovery Buoy
shackle
thimble
thimble
shackle
Support Buoy
Top Current Meter at 41'
shackle
thimble
B
125' 5/8" poly-propolene line
thimble
shackle
Bottom Current Meter at 171'
shackle
thimble
4' 5/8" poly-propolene line
thimble
shackle
swivel
6001b cement wgt
6' ½" chain
240' 3/8" nylon line
6' ½" chain
thimble
shackle
250 lb mushroom anchor
1'
C
Recovery Buoy
shackle
nylon block
thimble
shackle
2' pipe 2"
230' 3/8" nylon line

Figure 5-16. Arrangement of current meters and tackle, May 29, 1968.

A. Recovery buoy and support buoy of the surface current meter.

B. The bottom current meter and anchor. This buoy was missing when the instruments were recovered July 10.

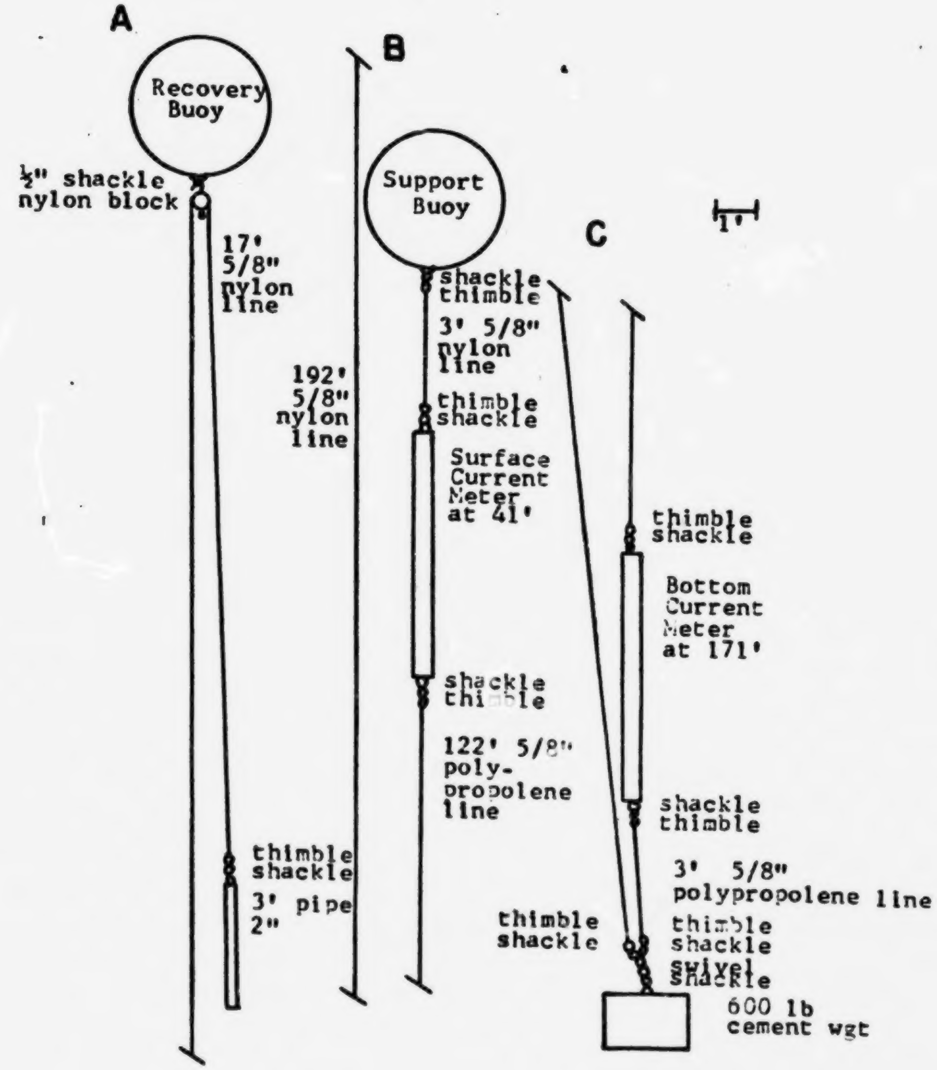

A
Recovery Buoy
½" shackle
nylon block
17' 5/8" nylon line
thimble
shackle
3' pipe
2"
B
192' 5/8" nylon line
Support Buoy
shackle
thimble
3' 5/8" nylon line
thimble
shackle
Surface Current Meter at 41'
shackle
thimble
122' 5/8" poly-propolene line
C
1'
thimble
shackle
Bottom Current Meter at 171'
shackle
thimble
3' 5/8" polypropolene line
thimble
shackle
thimble
shackle
swivel
shackle
600 lb cement wgt

Figure 5-17. Arrangement of current meters and tackle, July 1968.

A. Vertically held recovery buoy.

B. Support and auxilliary recovery buoy and surface current meter.

C. Bottom current meter, anchor and recovery line.

Table 5-7 **First 24 hours of current data at 41' at the experimental site, July 18, 1968.**

41' 7/18-9/19

	INTERVAL NUMBER		DIRECTION	ROTOR SPEED IN KNOTS
7/18/68 1600	1	AVERAGE	360	1.54
	2	AVERAGE	14	RANGE
	3	AVERAGE	18	(0.)
	4	AVERAGE	179	0.30
	5	AVERAGE	261	0.14
	6	AVERAGE	69	0.16
	7	AVERAGE	114	0.16
	8	AVERAGE	108	0.13
	9	AVERAGE	156	0.25
	10	AVERAGE	184	0.29
	11	AVERAGE	166	0.39
	12	AVERAGE	187	0.39
Low tide 2200	13	AVERAGE	170	0.23
	14	AVERAGE	197	0.42
	15	AVERAGE	208	0.36
	16	AVERAGE	224	0.27
7/19/68 2400	17	AVERAGE	230	0.26
	18	AVERAGE	190	0.33
	19	AVERAGE	245	0.40
	20	AVERAGE	259	0.39
	21	AVERAGE	274	0.37
	22	AVERAGE	290	0.43
300	23	AVERAGE	292	0.36
High tide	24	AVERAGE	302	0.40
	25	AVERAGE	309	0.43
	26	AVERAGE	298	0.41
	27	AVERAGE	313	0.40
	28	AVERAGE	311	0.33
	29	AVERAGE	322	0.42
	30	AVERAGE	323	0.41
	31	AVERAGE	318	0.44
	32	AVERAGE	340	0.50
	33	AVERAGE	333	0.32
	34	AVERAGE	319	0.37
Low tide 900	35	AVERAGE	301	0.49
	36	AVERAGE	314	0.40
	37	AVERAGE	307	0.35
	38	AVERAGE	303	0.27
	39	AVERAGE	328	0.30
	40	AVERAGE	317	0.15
	41	AVERAGE	310	0.31
	42	AVERAGE	288	0.32
	43	AVERAGE	334	0.11
	44	AVERAGE	100	0.09
	45	AVERAGE	25	0.14
	46	AVERAGE	347	0.28
	47	AVERAGE	62	0.31
	48	AVERAGE	349	0.29
High tide 1600	49	AVERAGE	9	0.33
	50	AVERAGE	39	0.12

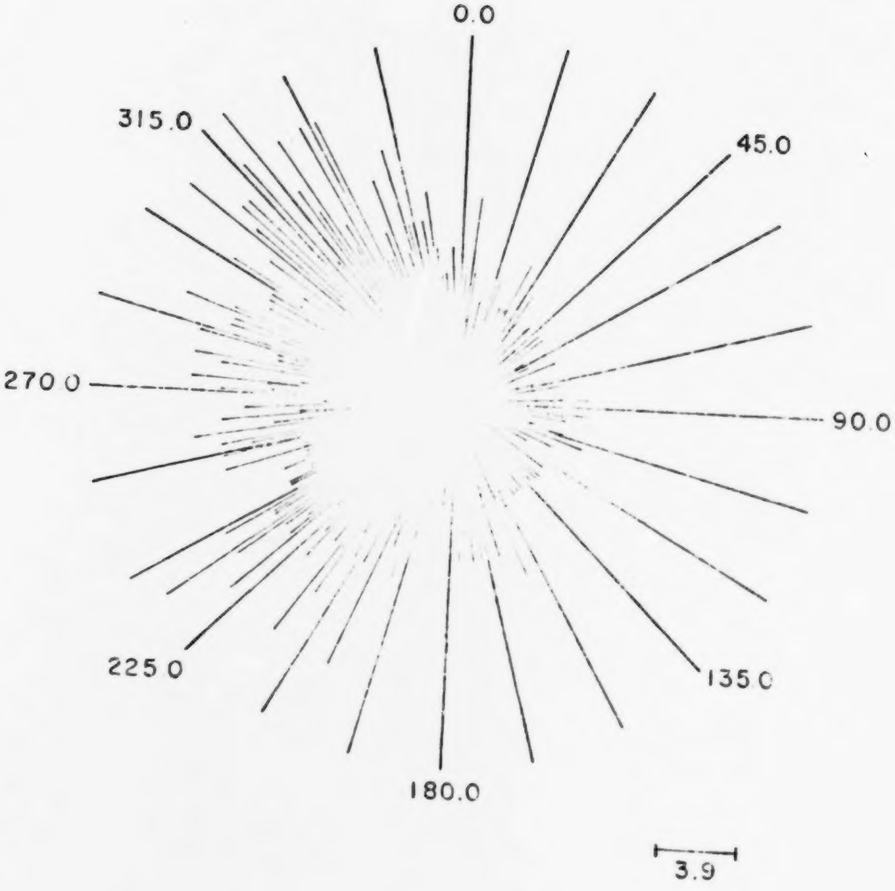


Figure 5-18. A polar coordinate histogram of current direction at 12.5 M (41 feet) depth between May 31 and July 10, 1968.

similar histogram. However, currents right at the surface appear to be a little faster than those at 12.5 M. Currents at 12.5 M averaged about 20.7 cm/sec (0.4 knots)(Figure 5-19). **Currents** measured at the surface after the meters lost their anchor were often higher than 51.7 cm/sec until the rotor broke. Currents at 52 M were restricted mostly to northeast and southwest directions (see Figure 5-7). **Current directions did not appear** to be directly related to tides (Table **5-8**). Maximum current velocities between May 31 and July 10 were just under 20.6 cm/sec (0.4 knots); the average velocity was about 5.2 cm/sec (0.1 knot) (Figure 5-20).

Wave Recorder

A 5-day Snodgrass wave recorder system consisting of control and recorder, transducer, and 458 M of cable **was** installed at Pt. Judith Coast Guard Station. The transducer was placed in 6M of water on the east side of the Point July 25, 1968 (Figure 5-21). Permission to do so was obtained from the Coast Guard, the U. S. Army Corps of Engineers, and the Rhode Island State Division of Harbors and Rivers. Data **were collected after** installation, except for brief periods when the chart paper either ran out or jammed.

Wind Recorder

Wind direction and velocity data were collected on station at 1/2 hour intervals from July 5, 1968 to August 21, 1968. However, **the instrument malfunctioned and the data were not usable.**

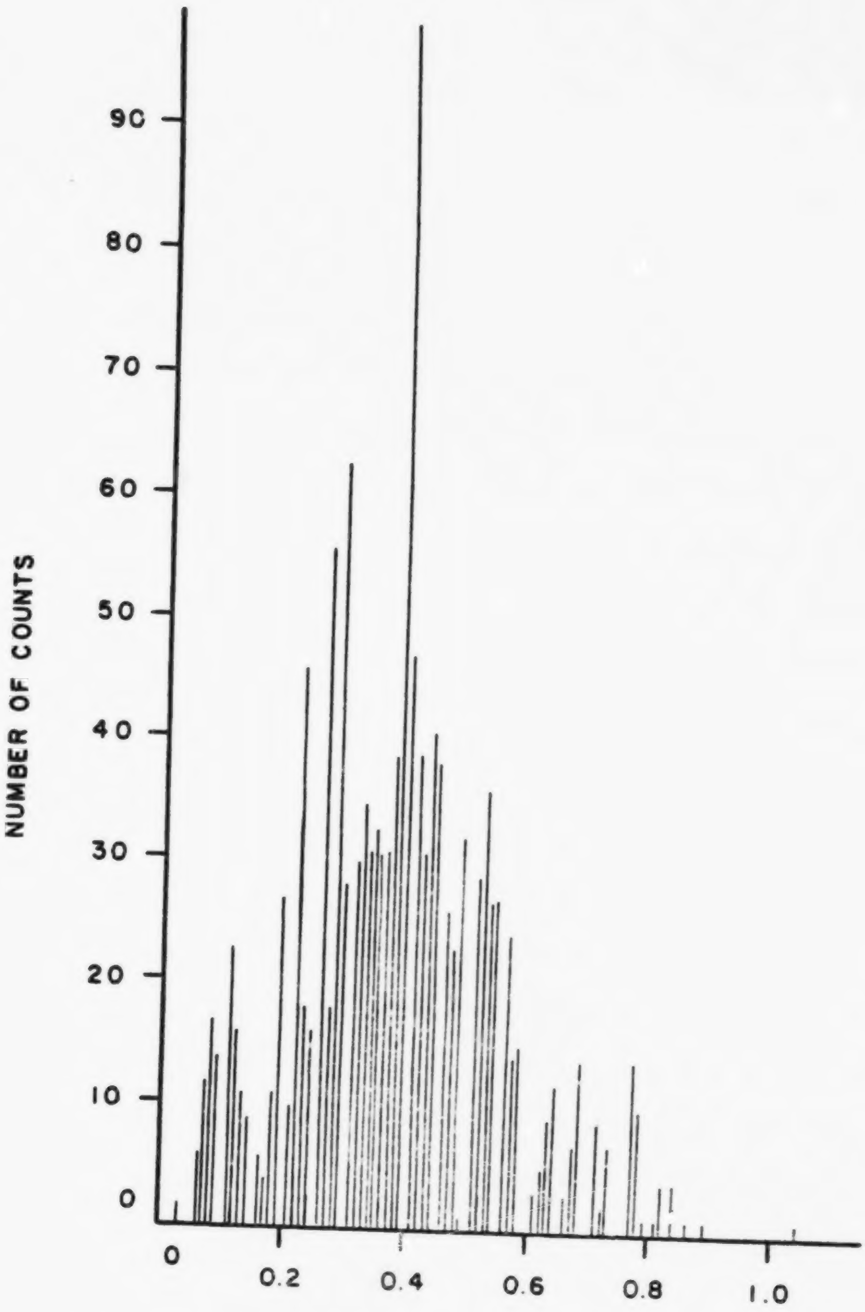


Figure 5-19. A histogram of rotor speed at 12.5 M (41 feet) depth at the Cox Ledge Station between May 31 and July 10, 1968.

Table 5-8 **First 24 hours of current data at 171' at the experimental site July 18, 1968**

VALIDITY INDICATORS	INTERVAL NUMBER		DIRECTION	ROTOR SPEED IN KNOTS
7/18/68 1600	1	AVERAGE	121	0.05
	2	AVERAGE	141	0.05
	3	AVERAGE	172	0.06
	4	AVERAGE	212	0.06
	5	AVERAGE	204	0.08
	6	AVERAGE	82	0.11
	7	AVERAGE	82	0.11
	8	AVERAGE	71	0.12
	9	AVERAGE	75	0.11
	10	AVERAGE	99	0.10
	11	AVERAGE	278	0.11
	12	AVERAGE	248	0.08
Low tide 2200	13	AVERAGE	236	0.11
	14	AVERAGE	247	0.10
	15	AVERAGE	250	0.09
	16	AVERAGE	341	0.06
2400	17	AVERAGE	307	0.03
	18	AVERAGE	308	0.03
	19	AVERAGE	308	0.04
	20	AVERAGE	308	0.03
	21	AVERAGE	6	0.04
RC	22	AVERAGE	38	0.05
7/19/68 300	23	AVERAGE	26	0.07
High tide	24	AVERAGE	14	1.28
	25	AVERAGE	2	1.14
	26	AVERAGE	360	0.08
	27	AVERAGE	7	0.07
	28	AVERAGE	14	0.06
	29	AVERAGE	84	0.07
	30	AVERAGE	80	0.13
	31	AVERAGE	75	0.10
	32	AVERAGE	60	0.09
	33	AVERAGE	55	0.10
RC	34	AVERAGE	51	0.13
Low tide 900	35	AVERAGE	53	0.12
	36	AVERAGE	49	0.15
	37	AVERAGE	61	0.11
	38	AVERAGE	47	0.17
	39	AVERAGE	74	0.15
	40	AVERAGE	78	0.10
	41	AVERAGE	77	0.11
	42	AVERAGE	94	0.13
	43	AVERAGE	79	0.11
	44	AVERAGE	70	0.07
	45	AVERAGE	28	0.09
	46	AVERAGE	21	0.08
	47	AVERAGE	15	0.05
	48	AVERAGE	12	0.03
High tide 1600	49	AVERAGE	60	(0.)
	50	AVERAGE	56	(0.)

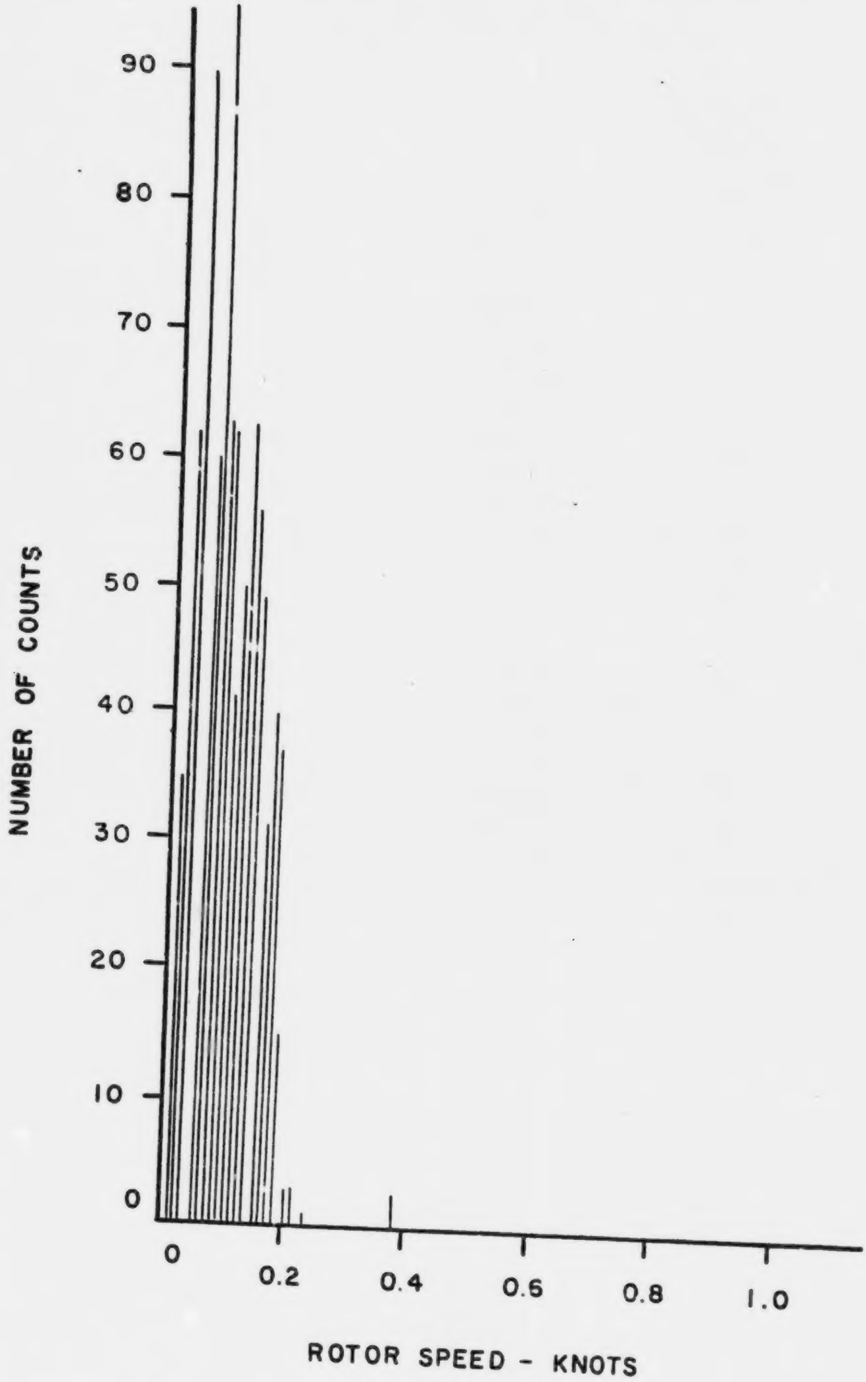


Figure 5-20. A histogram of rotor speed at 54 M (171 feet) at the experimental site between May 31 and July 10, 1968.

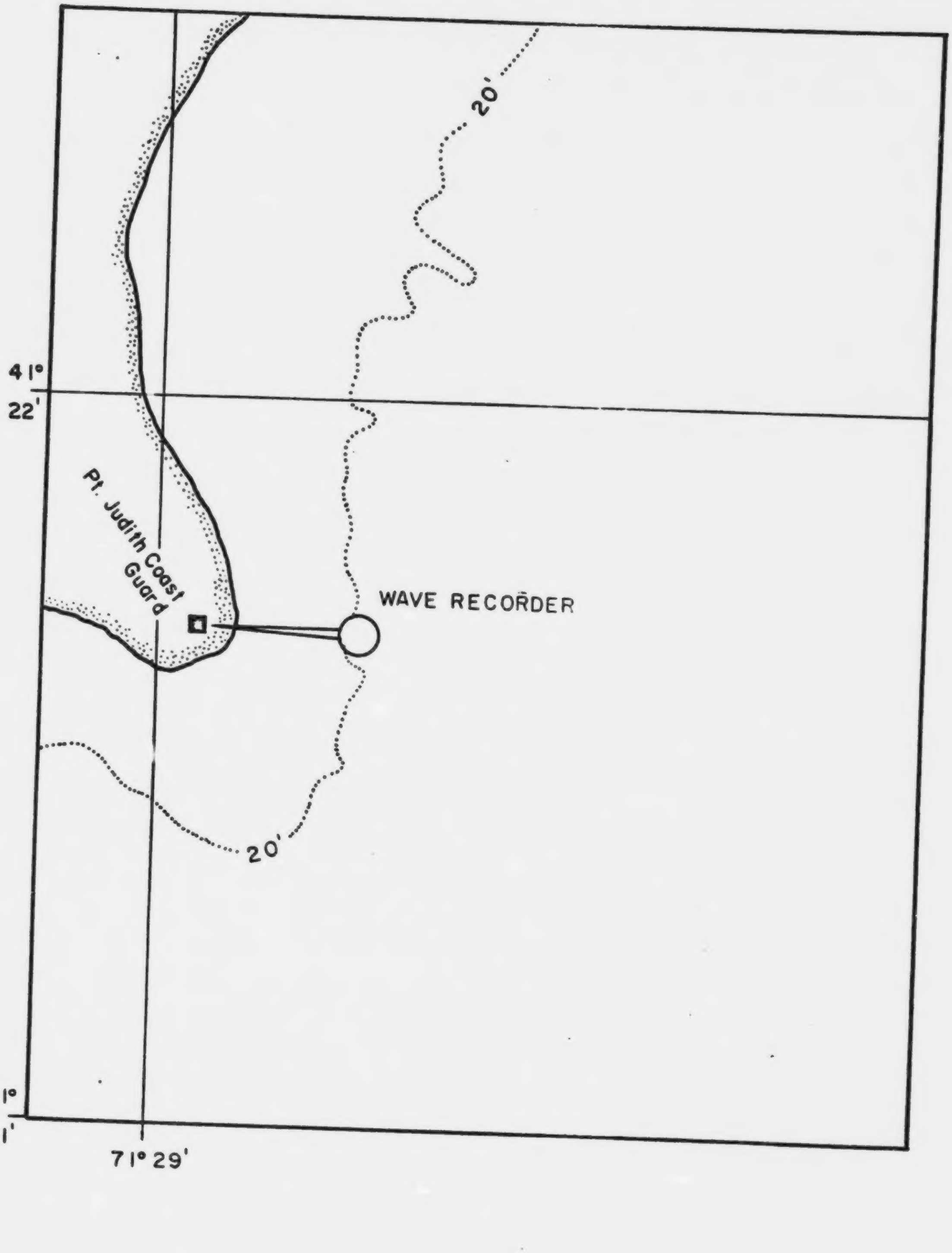

20'
41°
22'
Pt. Judith Coast Guard
WAVE RECORDER
20'
41°
21'
71° 29'

Figure 5-21. A chart of the location of the wave recorder at Pt. Judith, Rhode Island. -387-

Appendix 5-II. Report on Trend Surface Analysis off Point Judith, Rhode Island

Saul B. Saila

Introduction

This study was designed to provide a means for assessing the nature of the distribution of solid residues on the ocean floor. In spite of the fact that no large scale dumps of solid residue were made during the project period, it is apparent that some means must be available to empirically estimate the distribution and dispersion of these residues in an operational or pilot system. In lieu of discharging residues it was thought that a trend surface analysis of undisturbed sediments could illustrate the methodology, provide some information on sediment distribution over the initial test site, and perhaps provide some relationship between sediment distribution and water movements in the area.

The initial buoy location (test site) was at latitude 41° 21' and longitude 71° 32'. This site is approximately 1.7 miles south of Jerusalem, Rhode Island, and the mean low water depth is approximately 50 feet in the area of the buoy. Fig. 5-22 illustrates the site location as well as a one square mile systematic sampling grid of 100 stations around the buoy location. Table 5-9 lists the locations of each of the samples as indicated by sextant readings. The test site was located in this area in order to provide easy access by small boats as well as to permit relatively easy surveillance by divers. The oceanographic data gathering buoy located at the center of the site provided information on wind speed and direction, water currents and water temperature.

Sediment Sampling and Analysis

Positions at the sampling stations were located by means of sextant readings to prominent local landmarks. The first 30 samples were taken with a one-half yard construction bucket and the remaining stations were sampled with a weighted Peterson dredge. Sediment samples were removed from the samplers by inserting a 2 inch diameter coring tube of 6-9 inches length into the sediment when taken aboard the survey vessel.

Sediment samples were individually marked according to their location. They

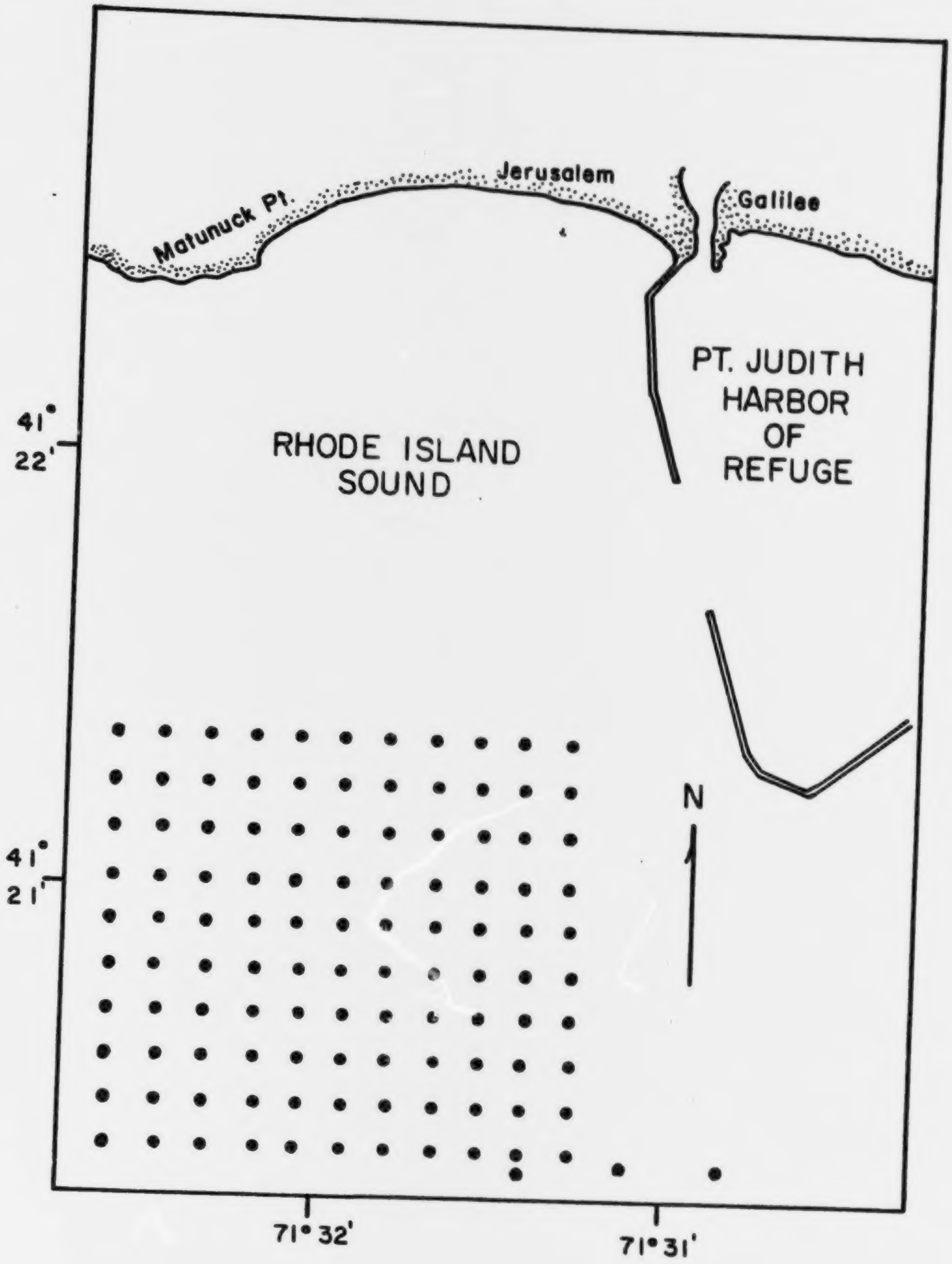

Matunuck Pt.
Jerusalem
Galilee
PT. JUDITH HARBOR OF REFUGE
RHODE ISLAND SOUND
41° 22'
41° 21'
N
71° 32'
71° 31'

Figure 5-22. Location of sediment sampling stations in the vicinity of the oceanographic buoy off Jerusalem, Rhode Island. (See Figure 5-1 for buoy site).

Table 5-9

Position of Sediment Samples Off Pt. Judith 9/1 - 10/67

No.	Long.			Lat.			No.	Long.			Lat.		
1	71°	32'	15,"	41°	21'	23"	26	71°	21'	44,"	41	21'	11"
1	71	32	24,	41	21	19	27	71	31	38,	41	21	08
2	71	32	17,	41	21	19.5	28	71	31	30,	41	21	08
3	71	32	7,	41	21	17	29	71	31	21,	41	21	08
4	71	32	96,	41	21	19	30	71	31	13,	41	21	08
5	71	31	53,	41	21	19	31	71	32	27,	41	21	04
6'	71	32	30,	41	21	33	32	71	32	18,	41	21	01
6	71	31	48,	41	21	17	33	71	32	10	41	21	02
7	71	31	35,	41	21	17	34	71	32	00,	41	21'	01
8	71	31	28,	41	21	17	35	71	31	55,	41	21	01
9	71	31	21,	41	21	17	36	71	32	47,	41	20	58
10	71	31	12,	41	21	19	37	71	31	38,	41	21	01
11	71	32	27,	41	21	14	38	71	31	30,	41	21	01
12	71	32	15,	41	21	15	39	71	31	21,	41	21	01
13	71	32	7,	41	21	13	40	71	31	13,	41	21	01
14	71	32	02,	41	21	14	41	71	32	27,	41	20	55
15	71	31	55,	41	21	14	42	71	32	18,	41	20	55
16	71	31	45,	41	21	13	43	71	32	09,	41	20	53
19	71	31	21,	41	21	14	44	71	32	06,	41	20	56
20	71	31	13,	41	21	14	45	71	31	55,	41	20	55
21	71	32	10,	41	21	14	46	71	31	46,	41	20	55
22	71	32	17,	41	21	17	47	71	31	58,	41	20	55
23	71	32	10,	41	21	08	48	71	31	30	41	20	55
24	71	32	02,	41	21	08	49	71	31	21	41	20	55
25	71	31	55.	41	21	08	50	71	31	13	41	20	55
51	71°	32'	27",	41°	20'	48"	76A	71°	31'	36",	41°	20'	51"
52	71	32	18,	41	20	48	77	71	31	38,	41	20	36
53	71	32	10,	41	20	48	78	71	31	30,	41	20	36
54	71	32	02,	41	20	48	79	71	31	21,	41	20	36
55	71	31	55,	41	20	48	80	71	31	13,	41	20	36
56	71	32	6,	41	20	47	81	71	32	27,	41	20	30
57	71	31	49,	41	20	37	82	71	32	18,	41	20	30
58	71	31	54,	41	20	31	83	71	32	10,	41	20	30
59	71	31	24,	41	20	47	84	71	32	02,	41	20	30
60	71	31	13,	41	20	48	85	71	31	55,	41	20	30
61	71	32	27,	41	20	42	86	71	31	46,	41	20	30
62	71	32	18,	41	20	42	87	71	31	38,	41	20	30
63	71	32	7,	41	20	42	88	71	31	30,	41	20	30
64	71	32	02,	41	20	42	89	71	31	21,	41	20	30
65	71	31	56,	41	20	49	90	71	31	13,	41	20	30
66	71	31	55,	41	20	47	91	71	32	27,	41	20	26
67	71	31	58,	41	20	35	92	71	32	18,	41	20	26
68	71	31	30,	41	20	42	93	71	32	11,	41	20	25
69	71	31	21,	41	20	42	94A	71	32	03,	41	20	21
70	71	31	06,	41	20	43	94	71	32	04,	41	20	24
71	71	32	27.	41	20	36	96	71	31	43,	41	20	20
72	71	32	18,	41	20	36	97'	71	31	38,	41	20	20
73	71	32	10,	41	20	36	97	71	31	31	41	20	20
74	71	32	02,	41	20	36	98	71	31	34,	41	20	21
75	71	31	55,	41	20	36	99	71	31	21,	41	20	24
							100	71	31	19,	41	20	20

were subjected to mechanical analysis according to the method of Krumbein and Pettijohn (1938). The analysis consisted primarily of sieving in a column of sieves arranged on the $\sqrt[4]{2}$ scale after the sample had been split and prepared by washing and drying.

The raw data obtained from the mechanical analysis were placed on cards and subjected to a computer program which contained various statistical techniques for particle size analysis. This program entitled "Master Statistical" was modified by the University of Rhode Island group in Geological Oceanography from several existing programs, and it is available from this source. The program calculates the percent sand, silt, clay and gravel of the sediment being analyzed, the phi percentiles, moment statistics, Folk statistics, Inman statistics and the data for drawing a frequency distribution curve. It also lists the phi increment, the weight of material for that phi size, the weight percent and the cumulative weight percent.

The results of this statistical analysis of raw data were carefully examined and it was judged that the standard deviation of the size composition of the particles, the percent sand, and the mean particle size would be utilized as inputs for the trend surface analysis program. That is, it was assumed that some measure of dispersion of the particles, mean particle diameter, and/or the percent sand in the sediments might show systematic changes within the sampled area which would be associated with the physical processes involved in their variation.

Trend Surface Analysis

In general terms trend surface analysis is a procedure for separating the relatively large-scale systematic changes in mapped data from essentially non-systematic small-scale variations due to local effects. The method can be applied to any contour type map, and has been used previously for analysis of gravity maps and isopach maps.

Trend surfaces are described by equations in which a dependent variable is a function of two independent variables. The mathematical operations of trend-surface fitting consist of finding the constants A, B, ..., J (Table 5-10) such that the least squares criterion is satisfied. In fitting a trend surface to the data, the dependent variable z, represents percent sand, mean size, or the standard deviation in our case and the independent variables x and y, represent map coordinates measured from some arbitrary origin. The map coordinates may be in any unit.

Trend surfaces may be classified according to degree. In this study surfaces up to and including sixth-degree were fitted. A first degree surface is a plane and contains only linear terms, whereas generalized second degree surfaces, containing both quadratic and linear terms, are either bowl-shaped or saddle shaped paraboloids. Higher degree surfaces are even more complex.

The goodness of fit of a trend surface may be expressed as the percentage reduction in the total sum of squares, which is given by the expression

$$100 \times \frac{\Sigma x^2 \text{ trend} - \frac{(\Sigma x \text{ trend})^2}{n}}{\Sigma x^2 \text{ obs.} - \frac{(\Sigma x \text{ obs.})^2}{n}}$$

where:

x_{trend} = values on trend surface at location of data points

x_{obs} = observed data values

n = no. of data values.

A perfect fit of the trend surface to the data points would be 100 percent of the total sum of squares.

For this study a program entitled, "FORTRAN IV and MAP Program for Computation and Plotting of Trend Surfaces for Degrees 1 through 6" by O'Leary, Lippert,

Table 5-10. General classification of trend-surface equations in which components are grouped according to degree. Letters A through J represent constants of equations, and x and y represent independent variables; z is dependent variable.

Surface	Dependent variable elevation	Linear Component	Quadratic Component	Cubic Component
First Degree (plane)	$z =$	$A + Bx + Cy$		
Second Degree (paraboloid)	$z =$	$A + Bx + Cy$	$+ Dx^2 + Exy + Fy^2$	
Third Degree	$z =$	$A + Bx + Cy$	$+ Dx^2 + Exy + Fy^2$	$+ Gx^3 + Hx^2y + Ixy^2 + Jy^3$

and Spitz (1966) was modified for use with the University of Rhode Island's IBM 360 Mod. 50. A brief explanation of program output is provided in the above-mentioned reference. Error measures for the various surfaces are computed and include TOTAL VARIATION, VARIATION NOT EXPLAINED BY SURFACE, VARIATION EXPLAINED BY SURFACE, COEFFICIENT OF DETERMINATION, COEFFICIENT OF CORELATION AND STANDARD DEVIATION.

Results of Trend Surface Analysis

This particular analysis deals with percent sand as the dependent variable. From an examination of the error measures table it is evident that there was no trend clearly discernable from any of the fitted surfaces. The distribution of sand was apparently affected by local phenomena. Empirical evidence for this was obtained by divers who indicated the presence of ripple marks in the area. The region studied (1 square mile) was apparently too small to permit a trend in the particle size distribution in the sediments. The error measures table also shows that even the 6th degree surface was able to account for less than one-half the total observed variability.

However, it seems clear that the approach suggested in this report has utility in attempting to determine the distribution of solid wastes in a defined area. No effort is made in this report to correlate the fitted surfaces with water movements in the area (current speed and direction). The reason is that the variation explained by the fitted surfaces was not adequate to permit such postulated associations.

In summary, it is suggested that the approach outlined in this report has utility in future solid waste distribution studies, and may be valuable in providing a technique for analysis of any variable which can be mapped on a coordinate system.

Literature Cited

Krumbein, W.C. and F.J. Pettijohn, 1938. Manual of Sedimentary Petrography, Appleton-Century Crofts, Inc., New York 549p.

O'Leary, M., R.H. Lippert, and O.T. Spitz, 1966, FORTRAN IV and Map Program for Computation and plotting of trend surfaces for degrees 1 through 6. Computer Analysis, No. 3. University of Kansas, 48 pp.

Appendix 5-III. Test Dumps and Surveys at Pt. Judith Station; 15 M Depth

Kern Kenyon

(1) Can Surveys

Test dump of 8/18/67

Sixty 360 cm^3 (12 oz) beer cans and a small pile of fine ash were placed on the bottom by SCUBA divers between 1200 and 1230 (DST) on 8/18/67. The divers made observations between 1200 and 1400 (DST). The cans were painted white with black numbers or letters on two sides. There were three types of cans with twenty cans of each type. The cans numbered 21-40 (Type 1) had their original configuration except for eight (8) holes, which were punched in the tops and bottoms to ensure complete flooding. The cans lettered A through T (Type 2) were completely flattened after their tops and bottoms had been cut off. The cans numbered 1-20 (Type 3) were filled with beach sand and sealed. The weight of the empty 360 cm^3 (12 oz) cans was about 56 gm (2 oz) each. The average weight of the sand filled cans was about 21.5 oz. All of the cans except for 1 of type 1 and 3 of type 3 (which were lost) were initially placed at the origin within the 1 M ring.

During a two hour period from 1200 to 1400 the cans were not observed to move. Small ash particles were observed to fly away with the current, but the ash pile which was only a few inches high was still in place at 1400.

The weather was hazy and warm with a gentle southwest breeze. Small (wave height 15-31 cm) short period (16 waves per minute) waves were observed (by eye) to run northeast during the two hour observation period.

Survey of 8/22/67.

On 8/22/67, 4 days after the test dump of 8/18/67, divers made a survey of the cans and the pile of ash. The observation period began at 1120 (DST) and lasted about 2 hours. Inside the metal ring 44 (out of 56) cans were found, 7 of type 1, 20 of type 2, and 17 of type 3. The pile of ash was smaller but still in place. The cans found outside the ring were distributed as shown in Table 5-11. The distance from the origin and direction were estimated by the divers. No compass or measuring tape was used.

A total of 12 cans, all of type 1 (original shape), were found outside the ring and had therefore undergone a slight displacement. Again the cans were not observed to move during the survey, although the divers said they could feel a slight surge on the bottom.

The weather during the survey was windy, foggy and cool. The sea surface was ruffled with a 0.3-0.5 M (occasionally 0.6 M) and short period (13 waves per minute) sea running roughly normal to the beach.

The surface tidal current during the observation period was 0.75 knot in the direction S 45°E. The tidal current at the surface in the 4 day period beginning on 8/18/67 varied in speed between 10.7 and 46.4 cm/sec. The bottom current was not recorded. The two main directions of the tidal current were roughly N 80° W and S 45° E, the strongest currents coincided with the direction S 45° E. There were no wave records during this period; however, some bathers reported that the waves were "pretty high" on 8/20/67.

Table 5-11

DISTRIBUTION OF TYPE 1 CANS ON 8/22/67
(4 days after the dump)

Can Number	Distance from Origin (M)	Direction of Displacement From Origin
21	0.61	S
23	3.97	N
24	1.22	N
25	2.44	N
26	0.61	S
29	0.92	W
30	1.22	NNW
31	0.92	N
32	0.92	N
35	3.36	N
39	0.61	W
40	1.83	NW

Survey of 8/31/67.

On 8/31/67, 13 days after the test dump of 8/18/67, divers made a second survey of the tin cans and the pile of ash. The observation period was from 1115 to 1300 DST. The divers found 16 cans, all of type 1 (original shape), outside the ring. The distribution of these 16 cans is given in Table 5-12 and Figure 5-7 (of text). The distance from the origin was measured to the nearest inch with a tape, and the direction was measured to the nearest 22.5 degrees with a hand compass. The pile of ash was still in place. Again the cans were not observed to move during the survey.

The positions of the 16 cans in Table 5-12 are plotted in Figure 5-7 to the nearest 15.2 cm. Also shown in Figure 5-7 (of the text) is the average displacement vector for the 16 cans; the magnitude of the average displacement vector is 2.2 M and its direction N 50° W. On the average, then, the 16 type 1 (original shape) cans moved slightly more than 15 cm per day during the 13 days since they were dumped. The two principal directions of the surface tidal current during the 13 day period, which were estimated from the current meter data, are shown in Figure 5-7 (of the text).

The maximum surface current in the 9 day interval between the survey of 8/22/67 and 8/31/67 was 38.6 cm/sec in the direction S 45° E. The bottom current was not recorded. The current record is not reliable after 8/29/67 due to fouling by marine growth, therefore the current during the observation period cannot be determined.

Table 5-12

DISTRIBUTION OF TYPE 1 CANS ON 8/31/67
(13 days after the dump)*

Can Number	Distance From Origin (M)	Direction of Displacement From Origin
21	4.8	SE
(22)	3.4	WNW
23	6.4	WNW
24	3.1	NNW
25	2.7	NW
26	3.7	SE
(28)	2.1	NW
29	3.4	WNW
30	3.4	WNW
31	2.1	NW
32	4.9	NW
(33)	3.4	N
35	3.4	WNW
(38)	2.7	NNW
39	2.7	NNW
40	3.4	WNW

* All of the 12 cans in Table 1 also occur in Table II. The 4 cans, which have numbers in parentheses in Table II, are cans which have moved outside the metal ring in the 9-day interval between the first (8/22/67) and the second (8/31/67) surveys.

The weather during the survey was foggy with a light breeze at the beginning. The fog cleared by 1230, and a southwest wind picked up causing whitecaps by 1300. A one hour (1200-1300) wave height record showed a small (15-31 cm) short period sea.

Survey of 9/19/67.

On 9/19/67, 32 days after the test dump of 8/18/67 and 3-4 days after the close passage of Hurricane Doria, the divers made a survey of the tin cans and ash pile. The observation period was 1200 to 1330 DST. All 17 of the sand filled (type 3) were found outside the ring, and none of the original shape cans (type 1) could be found. The ash pile had practically disappeared. Again, the cans were not observed to move during the survey.

The distribution of type 2 cans is shown in Table 5-13 and Figure 5-8. The distances in Table 5-13 were measured to the nearest 0.1 M with a tape, and the direction was measured to the nearest 22.5 degrees with a hand compass. The last 5 entries in Table 5-13 were measured relative to the buoy anchor, the first 15 were measured relative to the origin as in Table 5-11and 5-12. The can #F was recorded twice and can #Q was not recorded. The divers were unable to say whether one of the F's was really a Q or if can #F was measured twice.

The positions of the 20 flat cans in Table 5-13 are plotted in Figure 5-8 of the text to the nearest 0.1 M. Also shown in Figure 5-8 (of the text) is the average displacement vector, whose magnitude and direction are respectively 10 M and N 28° W. This represents an average displacement of about 30 cm per day for the 32 day period after the dump on 8/18/67. It should be observed

Table 5-13

DISTRIBUTION OF TYPE 2 CANS ON 9/19/67
(32 days after dump)

Can Number	Distance from Origin (M)	Direction of Displacement From Origin
M	1.95	E
A	1.53	NNE
F (?)	4.88	N
C	4.15	NNW
J	4.33	NW
N	5.79	NW
B,R	8.85	NW
H	9.56	NW
G	10.8	NW
T,E	7.94	NW
D	13.7	NW
K	11.0	NNW
F(?)	8.68	N

	Distance from the Buoy Anchor (M)	Direction of Displacement From The Buoy Anchor
L	4.43	WSW
P	5.89	W
O	9.77	SW
I	13.4	NW
S	8.04	WNW

that the average displacement vector points in the general direction of the beach. Since none of the flat cans had moved through 8/31/67, it is likely that their total net displacement occurred during a one day period (September 15-16) of large swell caused by Hurricane Doria. The two principal directions of the surface tidal current (also shown in Figure 5-7 [of the text]) are shown in Figure 5-8 (of the text) as well.

The weather during the survey was very calm, warm, and sunny. A 96 minute wave record, which began at 1200 DST, showed .1-.3 M swell with periods greater than or equal to 10 sec. During the observation period on 9/19/67, the bottom current speed was 15.5 cm/sec in the direction S 45° W, and the surface current speed was 20.7 cm/sec due west. The maximum surface current in the 11 day interval 9/8/67 to 9/19/67 was 46.5 cm/sec in the direction S 45° E, and the maximum bottom current was 25.8 cm/sec in the direction N 80° W. The surface current meter did not operate properly in the interval 8/29/67 to 9/8/67 due to marine growth on the sensor, and the bottom current was not recorded until 9/8/67.

Test Dump of 10/28/67.

A second test dump of 60 marked cans was made at the center stake within the 1 M ring (18.3 M south of the toroidal buoy anchor), i.e. the same origin which was used in the first test dump. The divers removed the 15 filled cans (type 3), which had not moved up to this time, and placed them together 0.3 M outside the ring in a southeast direction. The filled cans which had moved (two were seen) were left alone.

All cans were regular size (360 cm^3) beer cans which were painted cream color with black labels. Three different can shapes were used and there were 20 cans of each type. The cans labelled A through T (type 1) had their original configuration and were identical to the type 1 cans of the first dump except for different labels. The cans with the numbers 1-20 (type 2) were flattened after the ends were removed and were identical to the type 2 cans of the first dump except for the labels. A new type of can (type 4) with a bent shape was used in order to represent an intermediate configuration between types 1 and 2 and to represent the cans which are to be crushed after incineration. The bent shape was made by pushing down on the middle of one side of the can along a line perpendicular to the can's long axis until the two sides met. The can then looked as if it had been given a Karate chop: one side bent and the other side flattened. The type 4 cans were numbered 1-20 on the flat side. After the divers placed the cans at the origin, they observed that some of them started to move. However, they did not stay to watch.

During the two hours from 1200-1400 DST the wind blew from the southwest at force 2 or 5-10 mph, and there was a fairly heavy swell running from the south. The wave recorder was installed from 1237-1347 and measured wave heights up to 0.9 M and 1.2 M with periods slightly less than 10 sec. During 1200-1400 DST, the low current meter recorded a 15.5 cm/sec current, and its direction was changing from N 45° W to S 45° E. The data from the lower and upper meters is not considered reliable after 10/28/67 and 10/20/67, respectively, due to fouling by marine growth.

Survey of 10/31/67.

A survey was made at 1230 DST on 10/31/67, which was 3 days after the second dump and 74 days after the first dump. The divers attempted to record the position of the cans with a tape and compass, but it was difficult to do this because a large surge caused some of the cans to move back and forth during the measurement. None of this type 1 can was found, all of the type 4 cans had moved outside the 1 M diameter ring, and 6 of the type 2 cans had moved outside the ring. Of the 6 type 2 cans found outside the ring, 2 were found within 0.3 M of the ring in a northerly direction and 4 were found within 1.5 M of the ring in a southerly direction. The distribution of the 18 type 4 cans is shown in Table 5-14. The cans numbered 6, 11, and 12 were recorded twice. Either the cans were actually measured twice or the numbers were misread by the divers.

For the first time during a survey a number of cans were observed to move. The divers reported that 6 type 4 cans (numbers 4, 7, 12, 14, 19, 20) moved back and forth a distance of about 1 M with the passage of each wave. No net displacement was observed. A few flat cans (type 2) were also observed to move.

During the survey, the wind blew from the northeast at 24-32 kilometers/hr and a large swell was running out to the east. The wave recorder, which was installed from 1205 to 1530, showed 10 second waves with heights up to 1.04 and 1.53 M. Neither of the two current meters were functioning properly due to marine growth in the sensing elements.

Table 5-14

DISTRIBUTION OF TYPE 4 CANS ON 10/31/67
(3 days after the dump)

Can Number	Distance from Origin (M)	Direction of Displacement From Origin
1	0.92	N
12 (?)	4.73	NW
11 (?)	8.24	N
8	10.05	NWW
20	10.4	NWW
4	8.55	NNW
19	8.49	NW
7	10.05	NW
14	10.05	NW
11 (?)	6.41	NNE
6 (?)	4.57	NNE
6 (?)	6.10	NE
5	4.27	E
15	5.49	E
16	6.10	E
2	6.71	E
12 (?)	7.62	E
13	8.24	E

Survey of 11/7/67.

A can survey was made at about 1200 EST on 11/7/67, which was 10 days after the second dump and 81 days after the first dump. **The divers** measured directions with a compass, but the distances were estimated by eye. The cans were not observed to move during the survey. None of the type 1 cans were found, 19 of the type 2 cans were found, of which 12 were still inside the 1 M ring. The distribution of the 7 type 2 cans found outside the ring is given in Table 5-15.

A total of 14 type 4 cans were recorded, and all of them were found outside the ring. Their distribution is given in **Table 5-16. In Table 5-16 can 16 was recorded twice by mistake.**

Of the cans from the first dump, none of the type 1 cans was found, 11 type 2 cans were found, and 17 type 3 cans were found. The 15 type 3 cans, which were placed 0.3 M southeast of the ring on 10/28/67, were still in position. Can 12 was about 3 M north and can 5 about 2 M west of the origin. The type 2 cans were distributed as shown in Table 5-17. The first two cans in Table **5-17** were found lodged amid the pile of type 3 cans, but their numbers were not recorded.

The weather during the survey was cold, wet, and windy. The ocean surface was ruffled by small, locally generated waves.

Table 5-15

ESTIMATED DISTRIBUTION OF TYPE 2 CANS ON 11/7/67 (10 days after dump)

Can Number	Distance from Origin (M)	Direction of Displacement From Origin
8	0.92	NW
10	0.92	NW
16	1.22	S
17	0.92	SW
4	1.53	SW
19	1.53	WSW
14	3.66	N

Table 5-16

DISTRIBUTION OF TYPE 4 CANS ON 11/7/67
(10 days after dump)

Can Number	Distance from Origin (M)	Direction of Displacement From Origin
7	3.05	SE
16 (?)	4.57	SE
2	5.19	SE
9	6.10	SE
12	6.10	S
13	6.10	S
15	3.68	ESE
6	3.05	E
3	3.05	N
16 (?)	4.88	NW
4	12.20	NW
20	12.20	NW
10	3.05	N
8	6.10	N

Table 5-17

DISTRIBUTION OF TYPE 2 CANS ON 11/7/67
(81 days after dump)

Can Number	Distance from Origin (M)	Direction of Displacement From Origin
--	0.91	SE
--	0.91	SE
A	4.57	E
C	4.57	N
N	6.10	N
L	9.76	N
B	9.76	N

	Distance from Buoy Anchor	Distance of Displacement From Anchor
D	9.15	W
R	4.57	N
F	4.57	N
T	9.15	N

Calculations Made to Predict Can Movements at Other Depths.

Some preliminary calculations have been made in order to try to apply the results obtained for a water depth of 15 M (50 ft) to greater depths. Classical wave theory has been combined with wave observations in an attempt to estimate the number of days per year that tin cans might be set into motion along the bottom in various depths. A crude estimate of the net can movement has also been made.

Wave forces. According to Wiegel (1964) there are two main wave forces which act on a submerged object: 1) an inertia force F_I which depends on the water particle acceleration, and 2) a drag force F_O which depends on the water particle velocity. We will assume that the drag force is the dominant force and neglect the inertia force. The following simple calculation illustrates that this may not be a bad approximation.

From the information in Wiegel (1964, p. 250) we find that the ratio of the magnitude of the drag force to the magnitude of the inertia force is given for a cylinder by

$$\frac{|F_D|}{|F_I|} = \frac{C_D |u|^2}{\pi d |a|} \qquad (1)$$

where C_O is a drag coefficient, d the diameter of the cylinder, and u and a are the particle velocity and acceleration, respectively. According to classical Stokes' wave theory we have for u and a, evaluated at the ocean bottom

$$|u| = \frac{\pi H}{T \sinh kh} \qquad (2)$$

$$|a| = \frac{2\pi^2 H}{T^2 \sinh kh} \qquad (3)$$

where H is the wave height, T the wave period, h the water depth, and k = 2π/wave length is the wave number. Substitution of (2) and (3) in (1) gives

$$\frac{|F_D|}{|F_I|} = \frac{C_D}{2\pi \sinh kh} \frac{H}{d} \qquad (4)$$

Taking the following typical values for a situation in which the cans were observed to be moving,

H = 1.22 M

T = 10 sec

d = 6.35 cm

h = 15.2 M

sinh kh = 1

and a drag coefficient value C_o = 1.6 from Wiegel (1964, p. 258), equation (4) gives

$$\frac{|F_D|}{|F_I|} \approx 5$$

This ratio indicates that the drag force is dominant. The ratio would be larger than 5 for larger wave heights and periods.

Oscillatory can movement. If the drag force is the dominant wave force on a submerged tin can, then the water particle velocity is the pertinent parameter which determines the force. The force on a given tin can on the bottom will then be the same for different water depths if the particle velocity at the bottom is the same in all cases.

Using classical wave theory, four graphs have been prepared (Figs. 5-23-5-26)to exhibit the maximum water particle velocity at the bottom for different wave heights, wave periods, and water depths. Two contours of constant maximum particle velocity (15.2 cm/sec and 30.5 cm/sec) are plotted on each graph, whose axes measure wave height and wave period. Each graph corresponds to a particular water depth, and there is one graph for each of the four depths.

A twenty minute wave height record, taken on 10/31/67 when divers observed movement of bent and flat cans, was analyzed visually for wave heights and wave periods. 229 number pairs (a wave height and corresponding wave period is a number pair) were obtained and plotted on the graph for the 15 M (50 ft) depth. It was found that for 99 (43%) number pairs the maximum particle velocity exceeded 15.2 cm/sec and for 130 (57%) the maximum particle velocity was less than 15.2 cm/sec. For only 4 (2%) number pairs did the maximum particle velocity exceed 30.5 cm/sec. Therefore, as a working hypothesis we take 15.2 cm/sec as the critical maximum particle velocity which is just necessary to initiate the oscillatory movement of bent and flat (types 4 and 2) cans along the bottom.

In a similar manner more extensive wave data were used together with Figs.5-23-5-26 in order to estimate what percentage of the time the maximum particle velocity might be expected to exceed 15.2 cm/sec and 30.5 cm/sec for different water depths.

The data used were taken from Hogben and Lumb (1967), who have compiled about 2 million sets of sea state observations over the 8 year period 1953-1961. The data consist of visual estimates of

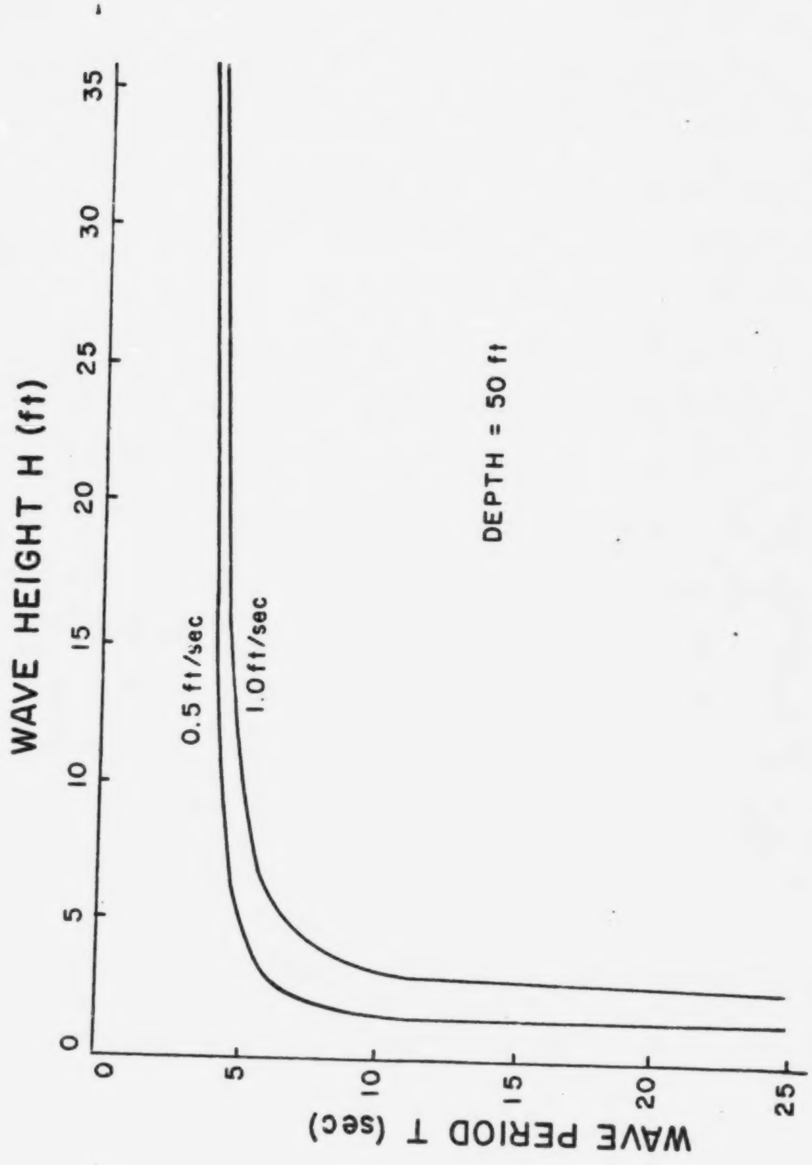


Figure 5-23. Maximum water particle velocity at the bottom for different wave heights and wave periods for a 15.2 M (50 feet) depth.

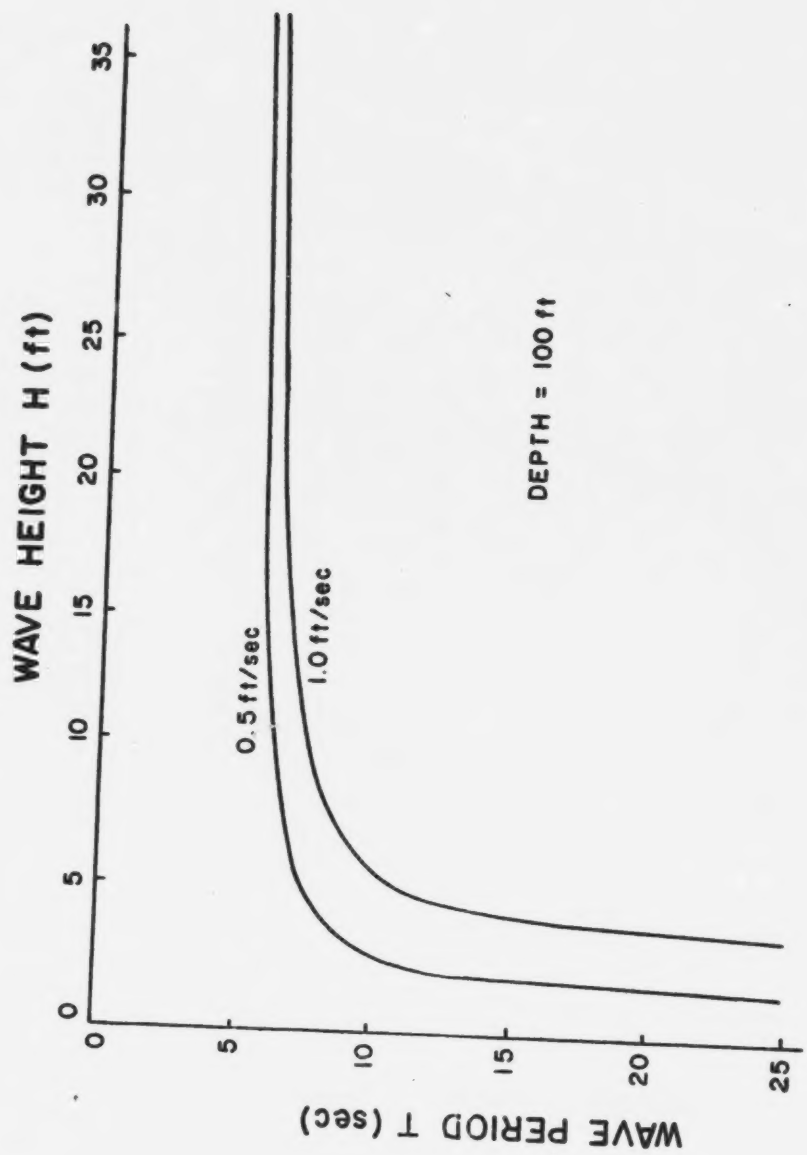


Figure 5-24. Maximum water particle velocities at the bottom for different wave heights and wave periods at 30.5 M (100 feet) depth.

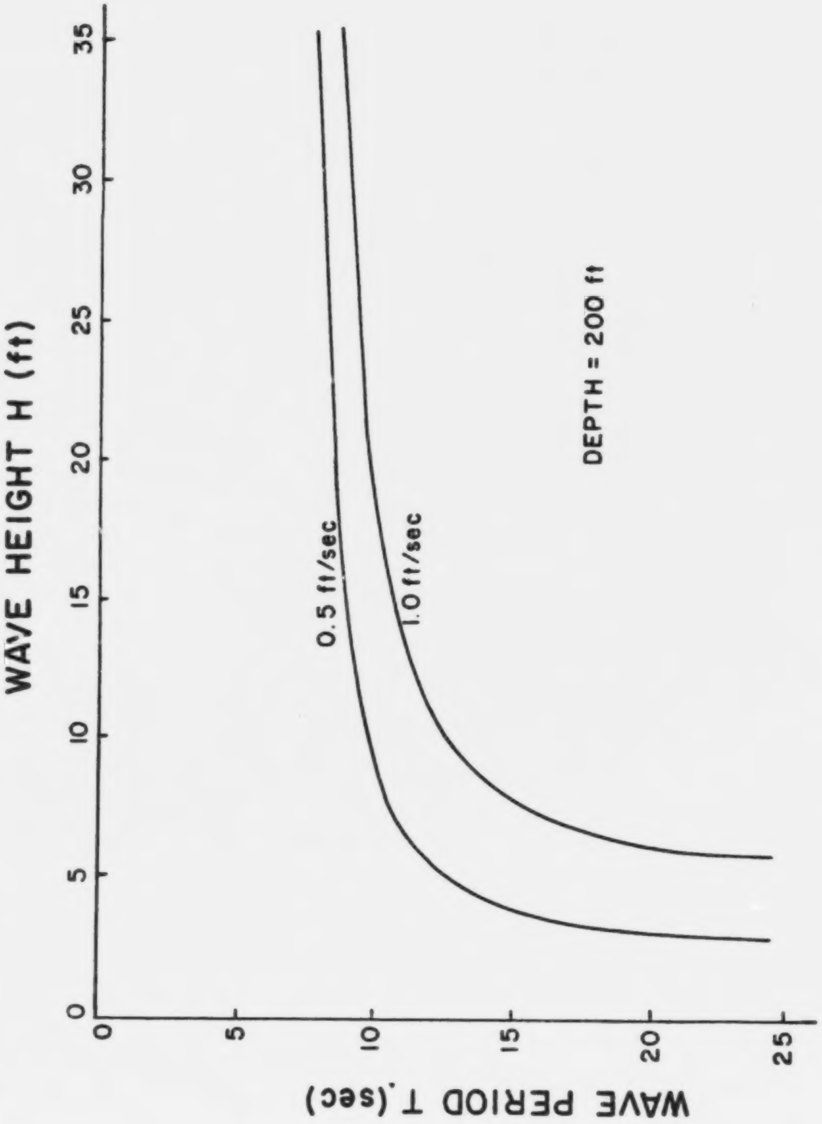


Figure 5-25. Maximum water particle velocities at the bottom for different wave heights and wave periods at 61.0 M (200 feet) depth.

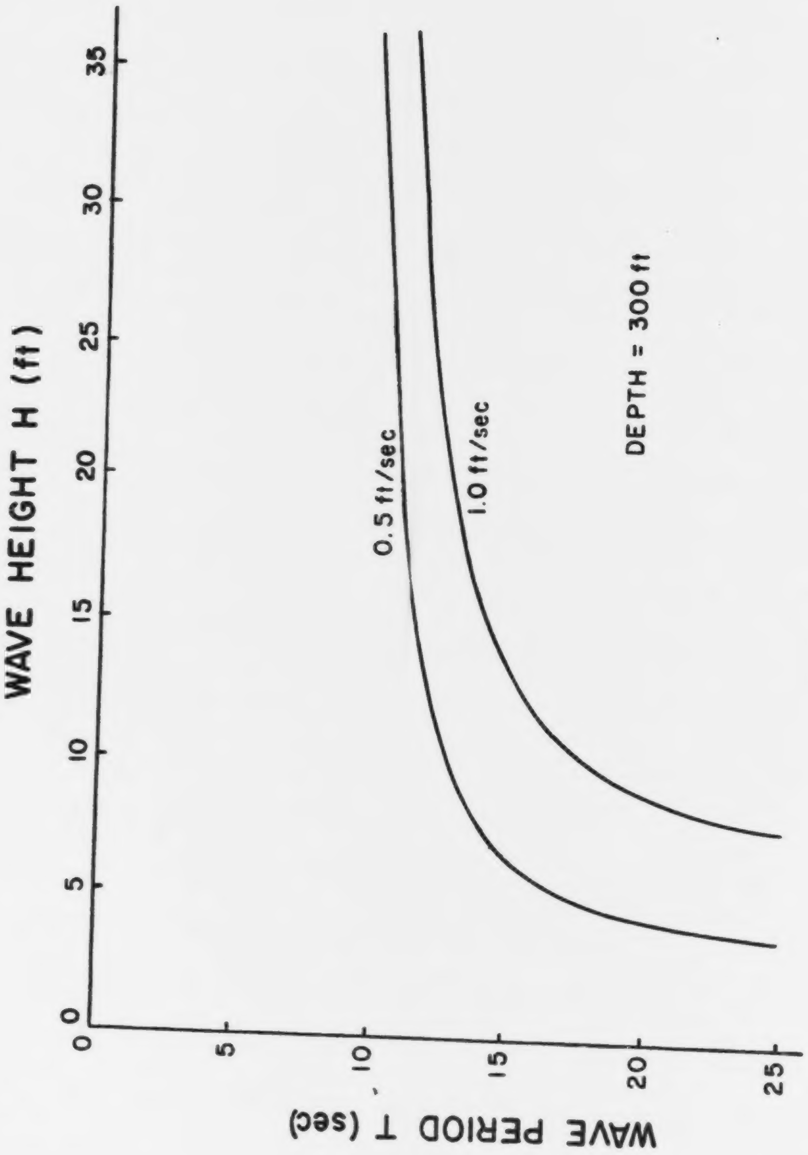


Figure 5-26. Maximum water particle velocities at the bottom for different wave heights and wave periods at 91.5 M (300 feet) depth.

wave height, period, and direction made from many ships according to an internationally agreed procedure. The data are presented in the form of tables for fairly large areas (60° squares and larger) over which sea conditions are assumed to be fairly homogeneous. In each table, wave period is given in eleven columns for periods from 5-21 sec (each column is 2 sec) and wave height is given in rows (each row is 0.5 m for heights less than 10 m and 1 m for heights above 10 m). The average values of wave period and height are reported, as obtained from the larger well-formed waves of the wave system being observed. The data are broken down into four seasons and 10° directional bands. The data consist of a large number of observations covering a wide area for a long period of time, and are therefore free from the local space-time characteristics of more accurate short term coastal observations.

First, the data were used for three areas (6,9,10) bordering the east coast of North America regardless of season or wave direction. Area 6 (40°-50° N, 40°-70° W) consisted of 35,885 number pairs of wave height and wave period observations, area 9 (30°-40° N, 70°-80° W) contained 5,794 observations, and area 10 (30°-40° N, 40°-70° W) contained 39,623 observations. By comparing the observations for the three areas with figures 5-23-5-26 the total number of observations was determined for which the maximum bottom particle velocity would exceed 15.2 cm/sec and 30.5 cm/sec for different water depths. These numbers are given in Table 5-18 in percent and days/year (in parentheses).

Table 5-18 is to be interpreted in the following manner. In general, the wave observations in areas 6,9, and 10 were made in the deep ocean where the water depth is the order of 4 km. If similar observations existed for ocean depths of 15.2 M, 30.5 M, 61.0 M and 91.5 M, then Table 5-18 gives the percentage of the observations for which the maximum bottom particle velocity would exceed 15.2 and 30.5 cm/sec. For example, if the area 10 observations held for a water depth of 61.0 M, then for 4% of the observations the maximum bottom particle velocity would exceed 15.2 cm/sec. Or, in other words, one might expect bent and flat tin cans (types 4 and 2) to rock back and forth 15 days per year on the average in water 61.0 M deep.

Table 5-18

Number of observations in percent (days/year) for which maximum bottom particle velocity exceeds given amount for different depths and different areas (all seasons included)

		Water Depth (M)			
area	particle velocity cm/sec exceeding	15.2	30.5	61.0	91.5
6	15.2 30.5	68(247) 49(177)	36(130) 22(79)	4.6(17) 1.7(6)	1.3(5) 0.3(1)
10	15.2 30.5	64(235) 43(156)	32(118) 18(67)	4(15) 1.3(5)	1.1(4) 0.3(1)
9	15.2 30.5	54(197) 30(110)	9.4(34) 4.2(15)	1.7(6) 0.4(2)	0.3(1) 0.1(0.6)

In a similar manner, Table 5-19 was made using data only from area 10 and breaking it down by season. The observations are fairly evenly spread over the four seasons. The number of observations per season are: Dec.-Feb. 9766, Mar.-May 10114, June-Aug. 10108, Sept.-Nov. 9635.

Table 5-19

Number of observations in percent (days/year) for which maximum bottom particle velocity exceeds given amount for different depths and different seasons (data for area 10 only)

		Water Depth (M)			
season	particle velocity (ft/sec) exceeding	15.2	30.5	61.0	91.5
Dec.-Feb.	0.5 1.0	71(248) 53(195)	41(150) 26(95)	12(45) 4.9(18)	3.9(14) 1.1(4)
Mar.-May	0.5 1.0	54(197) 36(116)	28(98) 14(53)	5.8(21) 1.6(6)	1.3(5) 0.3(1)
June-Aug.	0.5 1.0	26(96) 12(43)	7.4(27) 2.4(9)	0.7(2.5) 0.2(0.6)	0.2(0.6) 0.03(0.1)
Sept.-Nov.	0.5 1.0	49(174) 32(116)	22(79) 11(39)	4.9(18) 1.5(6.5)	1.3(4.8) 0.5(1.8)

Table 5-18 shows a rapid decrease with depth of the percentage of observations for which the maximum bottom particle velocity would exceed 15.2 cm/sec and 30.5 cm/sec. It drops from about 60% for a depth of 15.2 M to about 1% for a depth of 91.5 M. According to our assumptions we would expect, on the average, that a bent or flat can (type 4 or 2) would rock back and forth on the bottom more than 200 days/year in 15.2 M of water, but only a few (1-5) days/year in 91.5 M.

Table 5-19 shows that (at all depths) a much smaller percentage of the observations exceed the 15.5 cm/sec and 30.5 cm/sec levels during the summer season, June-August, than in the other three seasons, as might be expected.

Net can movement. A net displacement of tin cans has been observed by divers in water 15 M deep over time intervals as short as 4 days. The question is: on the basis of this information can we predict with certainty the net displacement one might expect at different depths under the same conditions? Only a tentative answer is possible. First, the phenomenon is complicated and our general understanding of it is poor. Second, our observations are not complete in that we were not able to monitor wave height continuously. Therefore, we have no idea how large the waves were between observations, during which time the cans underwent a net displacement.

The mechanisms by which cans are moved a net distance by waves is probably related to the mechanism by which the fluid particles undergo a net displacement in a given time. The particle motion associated with surface gravity waves consists of two parts: an oscillatory motion plus a small drift velocity, called mass transport velocity, in the direction of propogation of the waves. However, a tin can is not an idealized fluid particle, but it is an object which rolls and bounces along an uneven bottom whose roughness elements have the same characteristic dimensions as does the can. Another complication is the fact that tidal current speeds felt by the object can be the same order of magnitude or larger than the bottom mass transport velocity. Therefore, the effect of tidal currents on the net movement of cans may be as great or greater than the effect of waves, once the waves have initiated can movement.

A crude estimate of the net displacement to be expected for flat cans can be made on the basis of the survey of 9/19/67. It was observed that the average net displacement of twenty flat (type 2) cans was 10 M (32.8 ft) during a 19 day period. This movement occurred most likely during a one day period of large swell generated by Hurricane Doria to the south. In order to estimate what fraction of the water particle mass transport velocity this 10 M/day (32.8 ft/day) represents, the following calculations have been made.

First, the classical expression for the mass transport velocity U evaluated at the ocean bottom is

$$U = \frac{\pi^3 H^2}{g T^3 \tanh kh \sinh^2 kh}$$

where the notation is the same as before. Next from figures 5-23 to 5-26 the wave height H (ft) necessary to give a maximum bottom particle velocity of 15.2 cm/sec (0.5 ft/sec) (for which the cans are assumed to be moving) is shown in Table 5-20 for several depths h (ft) and wave periods T (sec).

Table 5-20

Wave height H (ft) necessary to give a maximum bottom particle velocity of 15.2 cm/sec (0.5 ft/sec) for different depths h (ft) and periods T (sec)

T(sec) h(ft)	M	7	10	13	16	19
50	15.2	2.16	1.58	1.42	1.35	1.32
100	30.5	7.08	2.99	2.34	2.12	2.00
200	61.0	83.0	9.65	4.80	3.65	3.24
300	91.5	114.0	32.2	9.60	5.86	4.67

Then, using Table 5-20 and the equation for the bottom mass transport velocity, Table 5-21 was prepared. Table 5-21 gives the bottom mass transport velocity U for different depths and wave periods when the maximum bottom particle velocity is 15.2 cm/sec (0.5 ft/sec).

Table 5-21

Bottom mass transport velocity 10^3 x U (ft/sec) when maximum bottom particle velocity is 15.2 cm/sec (0.5 ft/sec) for different depths h (ft) and periods T (sec)

T(sec) h(ft)	M	7	10	13	16	19	$10^3\overline{U}$ (ft/sec)	M/sec
50	15.2	3.98	3.52	3.47	3.26	3.26	3.50	9.2
100	30.5	3.56	2.79	2.52	2.42	2.30	2.72	8.3
200	61.0	2.95	2.54	2.06	1.87	1.77	2.24	6.8
300	91.5	3.10	2.46	1.43	1.67	1.53	2.14	6.4

The last columns in Table 5-21 give the average transport velocity $\overline{U}$ (averaged over the 5 wave periods) at each depth. Based on $\overline{U}$ the average distance $\overline{d}$ that a water particle at the bottom would travel in one day for different depths is given in Table 5-22.

Table 5-22

Values for different depths h of distance $\overline{d}$

h		$10^3\overline{U}$		$\overline{d}$		0.1 $\overline{d}$	
ft.	M	ft/sec	M/sec	ft/day	M	ft/day	M/day
50	15.2	3.50	9.2	302	98	30.2	9.8
100	30.5	2.72	8.3	235	72	23.5	7.2
200	61.0	2.24	6.8	194	59	19.4	5.9
300	91.5	2.14	6.4	185	56	18.5	5.6

Table 5-22 indicates that the average water particle displacement in one day at 15.2 M would be about 91.5 M when the maximum bottom particle velocity is 15.2 cm/sec (0.5 ft/sec). Assuming that the twenty flat cans (type 2) mentioned earlier moved an average of 10 M (32.8 ft) in one day and that the maximum bottom particle velocity was 15.2 cm/sec (0.5 ft/sec), the flat cans moved about 1/10 as far as a water particle on the average. The last column in Table 5-22 gives 0.1 $\overline{d}$ for comparison

Now, from Table 5-17 we compute the average number of days per year (based on a straight average of areas 6, 9, 10) when the maximum bottom particle velocity is expected to exceed 15.2 cm/sec

(0.5 ft/sec) for different depths. Column 2 in Table 5-23 shows $\bar{t}$ (days/year). Finally, assuming that flat cans (type 2), only, move when the maximum bottom particle velocity exceeds 15.2 cm/sec (0.5 ft/sec) and that they drift 0.1 times as far as a fluid particle, we calculate the average displacement $\bar{I}$.

$$\bar{\mathcal{L}} = 0.1\,\mathcal{L}\,\bar{t}$$

$\bar{I}$ is the average distance that a flat can might be expected to travel in one year for different depths, based on observations in the northwest Atlantic. This net displacement would be in the mean direction of wave propogation since the effect of tidal currents has been neglected. Column 3 in Table 5-23 gives $\bar{I}$ for different depths.

Table 5-23

Average time $\bar{t}$ (days/year) and displacement $\bar{I}$ of flat cans (type 2) in different depths h based on observations in the northwest Atlantic

h		$\bar{t}$	$\bar{I}$	
ft	M	day/year	mi/year	kilometers/year
50	15.2	226	1.29	2.060
100	30.5	127	0.57	0.910
200	61.0	13	0.048	0.077
300	91.5	3.3	0.012	0.019

__Discussion__. The two principal results of the calculations are contained in Tables 5-18 and 5-23 Table 5-18 is based on classical wave theory and wave observations in the northwest Atlantic. It indicates the percentage of observations in percent and in days per year for which the maximum particle velocity at the bottom would exceed 15.2 cm/sec (0.5 ft/sec) and 30.5 cm/sec (1.0 ft/sec) for different depths. Table 5-18 can be interpreted as giving the average number of days per year that a bent (type 4) or flat (type 2) can would be set into motion by wave forces, if the following assumptions are made. 1) The wave force on a can will be the same at different depths and for different wave heights and periods provided the particle velocity at the can is the same. This means that the drag force is assumed to be large compared to the inertia force. A calculation based on empirical information for cylinders suggests that this may be true for the tin can. 2) The critical maximum bottom particle velocity just necessary to start a bent or flat can moving is 15.2 cm/sec (0.5 ft/sec). This is an estimate based on a 20 minute wave record which coincided in time with the observation of oscillatory can movement along the bottom in water 15 M (50 ft) deep.

Table 5-23 gives the average distance that a flat (or bent) can might be expected to move in one year for different depths based on the assumptions stated previously. The relative decrease in net displacement with depth is probably more meaningful than the absolute numbers for each depth. In addition to the assumptions made in the interpretation of Table 5-18, Table 5-23 depends on the following assumptions. 3) The net displacement is due solely to wave forces, and 4) The displacement is one tenth of the average net displacement of a water particle at the bottom when the maximum bottom particle velocity is 15.2 cm/sec (0.5 ft/sec.).

Assumption 3) needs discussion. The neglect of the effect of tidal currents on the net displacement of cans in Table 5-23 is serious. It is obvious that tidal currents do have an important effect.Figure 5-7 (of the text) shows that although the average net displacement of 16 round cans (type 1) 13 days after dumping was about 2.1 M (7 ft) toward the northwest, 2 cans moved 3.7 M (12 ft) and 4.6 M (15 ft) toward the southeast. A wave mechanism alone predicts a net displacement in the direction of wave propogation, which would be generally toward the northwest in the vicinity of Pt. Judith. Therefore, the movement of 2 cans toward the southeast cannot be due to waves alone. However, the average direction of the outgoing tide at the observation point is toward the southeast, and from this we infer that influence of tidal currents may be important.

Figure 5-8 (of the text) shows the net displacement of flat cans (type 2) over a 19 day interval. We have suggested that this displacement probably took place during a one day period of large swell generated by hurricane Doria to the south. If this is true, one would expect the waves at the observation point to have travelled in a fairly narrow directional band toward the north, and therefore one would also expect the can distribution to have a narrow directional band on the basis of a pure wave mechanism. However, the can distribution had a broad directional band of 135 degrees, and the broadening of the band is probably due to the tidal currents.

The tidal current effect in coastal regions might be oversimplified as follows. Near the shore, the waves propagate nearly perpendicular and the tidal currents nearly parallel to the shore line. The waves will tend to move material on the bottom toward the shore, and the tidal currents will tend to scatter the material parallel to the shore. The relative magnitudes of the on-shore and along-shore movement to be expected under given conditions is not known. Figures 5-7 and 5-8 (of the text) suggest that for surface tidal currents of up to 51.6 cm/sec (1 kt) and a depth of 15.2 M (50 ft) the wave effect may be somewhat more important than the current effect.

Both wave and current effects should decrease in deeper water. If the tidal currents are the same at the bottom, one would expect that the current effect would become relatively more important than the wave effect in deeper water. This is due to the fact that the net water particle velocity (mass transport velocity) decreases with depth much faster than the orbital particle velocity. Thus, in deeper water the orbital velocity could still be sufficient to start a can rolling back and forth, but the tendency for a net movement would be much reduced. However, tidal currents also tend to become weaker in deeper water, so it is difficult to make any prediction about the relative importance of wave and current effects on object-displacement in different water depths. Both effects decrease with depth, though, because the wave effect decreases with depth and the current effect can't operate unless the wave effect is present (it was observed that the tidal currents are not able to move the cans in the absence of waves).

Assumption 4 states that a flat or bent can will move 0.1 times as far as a theoretical water particle. This assumption is based partially on observation, partially on classical wave theory, and partially on hypothesis. One might expect a large variation in the factor 0.1 for objects with different shapes and weights and for different types of ocean bottom.

REFERENCES

Hogben, N. and F. E. Lumb 1967. Ocean Wave Statistics, D. R. Hillman and Sons, Ltd., London, 263 pp.

Wiegel, R. L. 1964. Oceanographical Engineering, Prentice Hall, Inc., New Jersey, 532 pp.

4. Trial Dump of Marked, Unsegregated Residue at 15 M depth

Candace Oviatt

A trial dump of about 485 Kg of residue was made to determine the nature of its distribution and movement on the bottom.

Before the residue was dyed it was dried on polyethylene sheets in the sun for two weeks. Visual examination of the residue indicated about 40% ash, 20% cans and iron objects 30% partially burned paper and cloth, and 10% miscellaneous. An electric cement mixer was used to combine anthracene dye with residue. Eight liters of chloroform were mixed with 15-25 gm of dye. One to two liters of solution were mixed with two 19 l pails of residue No attempt was made to dye large iron objects or clumps of paper and rags. The dye solution was mixed with the residue for 5 minutes and then allowed to dry for 5 minutes. Nine 190 l drums of residue were dyed.

Bottom collectors were placed on cardinal and intercardinal radii about the center of the dump site. Collectors were placed at 7.6 M (25 feet), 15.2 M (50 feet), 30.5 M (100 feet) and 61.0 M (200 feet). Each collector radius was composed of 4 collectors attached together by measured cod line. Divers attached this line to the center stake on the bottom while a Boston Whaler on the surface ran out in the proper direction dropping the collectors at the proper intervals. Divers staked each collector radius at 30.5 M and 61.0 M from the center stake. Each collector was a 2.8 l plastic container cemented into a 23 cm diameter aluminum tin. The cod line was attached to galvanized screweyes on either side of this line. The center of the dumpsite was located 122 M north of the oceanographic buoy.

The nine drums of residue were dumped 10/31/67 in four minutes from the Rhode Island Marine Fisheries Vessel, the Wanderer. The wind was from the northeast at 24-40 kilometers/hr, the sea swell was from the east and averaged 1 M, the largest swells were about 1.68 M; the tidal current was running out toward the east-southeast. The data collected during the dump indicated wave height, surface and bottom current direction, wind direction and velocity. Photographs were taken from the boat, a helicopter, and by divers.

Appendix 5-IV Test Dumps and Survey at Cox Ledge Station; 54 M Depth

Candace Oviatt

PC-3B Submarine

A two man submersible was used to observe model objects during four survey periods. Specifications for the vehicle are shown in Figures 5-27 and 5-28. This survey method was used to observe any movements of the objects placed at the experimental dumpsite.

Surface and Underwater Marker Configuration

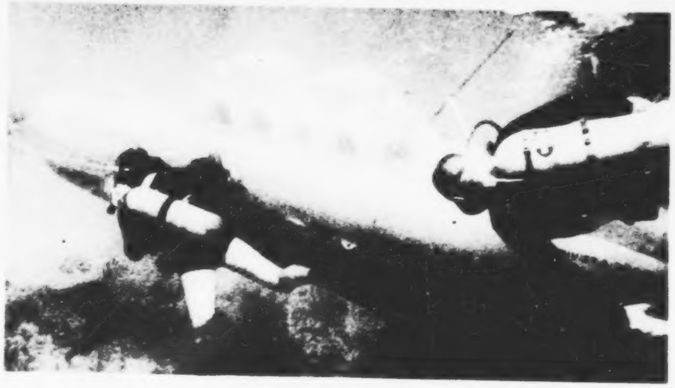
The site was marked off in a square configuration by buoys which were designed to remain vertical over their anchors. Red and white mooring balls with a single nylon block marked surface positions. The balls were anchored with 150 pound mushroom anchors by 0.95 cm nylon line which led through the nylon block to a 0.5M length pipe weight. West and East markers were placed 152M from a watermarker located 244 M south of the toroid buoy (Figure 5-29). Eighteen lettered markers were placed on the bottom to facilitate positioning of the submarine at 30.5M and 61.0M circumference from the center marker (Figure 5-30). Since the markers were dropped from a surface vessel with variable rpm's and unknown compass accuracy into a substantial surface current, the markers did not neccessarily land at their mapped positions. An additional 30 markers were placed in July -- numbers 1-15 in a south to north orientation and 16-30 in an east to west orientation (Figure 5-31).

SPECIFICATIONS

PERRY CUBMARINE®

PC3B

Figure 5-27



DIMENSIONS

Length	22'	o.a.
Beam	3'6"	
Draft surfaced	3'6"	
submerged	5'9"	
Weight on trailer	5500	lbs
Displacement surfaced	6050	"
submerged	7750	"
Payload up to	750	"

OPERATING CHARACTERISTICS

Operating Depth 600'
Tank Tested to 900' unmanned, 750' manned.
Dive and Rise rate - 2' per second
Turning circle - one boat length

SPEED

	Speed		Time		Distance	
	Surf'	Subm'	Surf'	Subm'	Surf'	Subm'
Full Power	4.5 knots	4	2 hrs.	2 hrs.	9 miles	8 miles
Cruising	3	2	4	4	12	10
Slow	2	1¾	10	10	20	17½

(Up to double this range is available at extra cost)

CONSTRUCTION

Main Hull ½" plate and heads A212 steel
Canopy ¼" plate, ⅜ heads A212 steel
Motor Room, Battery Comp. ¼" plate and heads A212 steel
Hatch Trunk ½" S.S. ASTM A-351 casting
Hatchs, Almag 335 casting
Port Holes, Plexiglass cones 1½" thick 8" and 6" dia.
Trim Tanks ¼" A212 steel
Main Ballast Tanks 11 and 12 gage A285
Fairwaters - Fiberglass

PROPULSION

Motor - Allis Chalmers 7 hp, 36v, 855 rpm, 180 amp #53-804-519
Batteries - Ten 95 amp. hr. lead acid.*
Motor Controls - Allis Chalmers PWM infinitely variable speed control.

*72 Silcad or 100 Silvercel are available at extra cost

INSTRUMENTS & GAGES-

Compass - Bendix Magnesyn remote reading
Depth Gages - (2) Helicoid 400' & 900'
Depthmeter - 60' -60 fathom Triton
Clock - 8 Day sweep 2nd hand Aircraft type
Volt and Amp. Meters - General Electric
Hydrogen Detector - Mine Safety Appliance Co. explosimeter model 3-4
Altimeter to measure cockpit pressure.

These instruments are considered standard with the vehicle.
Other instruments may be needed to perform particular missions.
Perry personnel are prepared to aid in the selection, fabrication, and installation of additional instrumentation as needed for particular missions.

CONTROLS-

Airplane type controls operate rudder and bow planes through master and slave hydraulic system, permitting excellent maneuvering ability while underway at 1 knot or more. Hovering motors available for right, left, up and down in the bow, and up and down amidships.

TRIM SYSTEM-

Trim Tanks - Two 200 lb. each fore and aft, 9' apart. Can be blown or pumped to or from sea or from one tank to the other.
Trim Pump - Hypro 6 gpm at 400 psi.
Motor - Milwaukee 2½ hp, 36v, 60 amp, 900 rpm.
Valves and piping are stainless steel or other non-corrosive material.

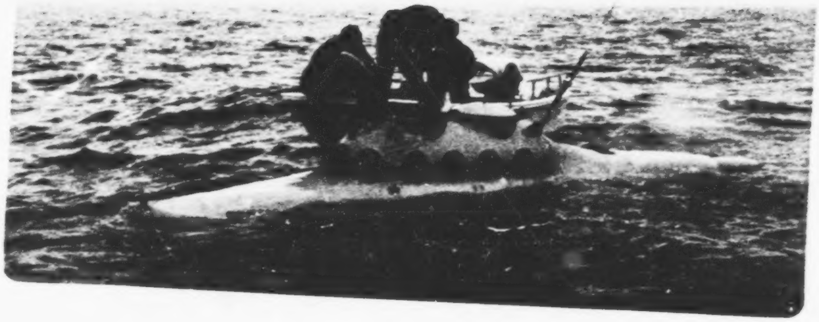


Figure 5-28. A view of the PC-3B Submarine.

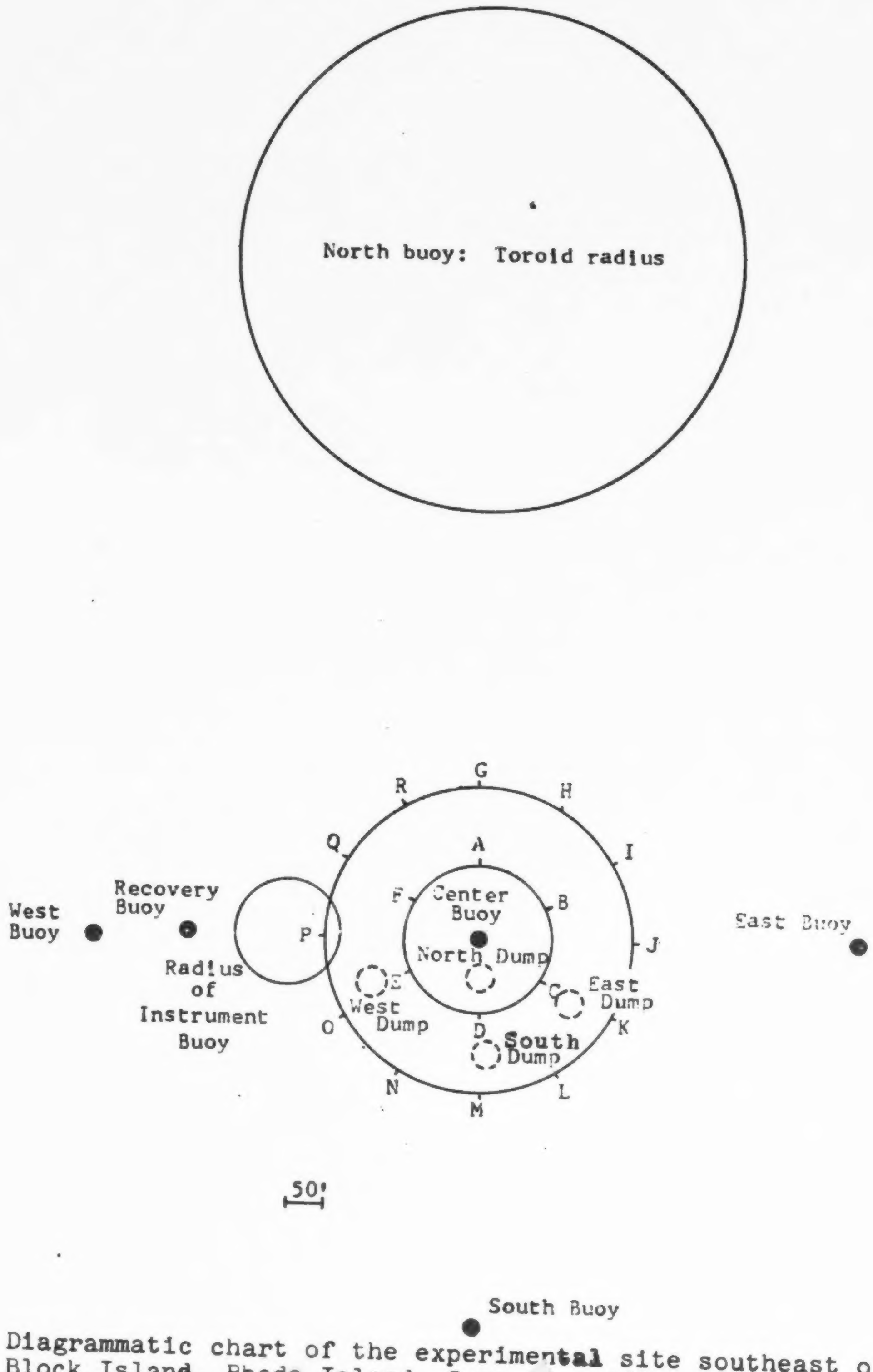

North buoy: Toroid radius
R
G
H
Q
A
I
F
Center Buoy
B
West Buoy
Recovery Buoy
P
J
East Buoy
North Dump
Radius of Instrument Buoy
E
C
East Dump
West Dump
O
D
K
South Dump
N
M
L
50'
South Buoy

Figure 5-29. Diagrammatic chart of the experimental site southeast of Block Island, Rhode Island, June 19, 1968. Letters indicate the position of underwater markers. Buoy radii indicate the scope of anchor lines. Solid small circles indicate positions of vertically held buoys. Dashed circles indicate the estimated positions of the four dumps.

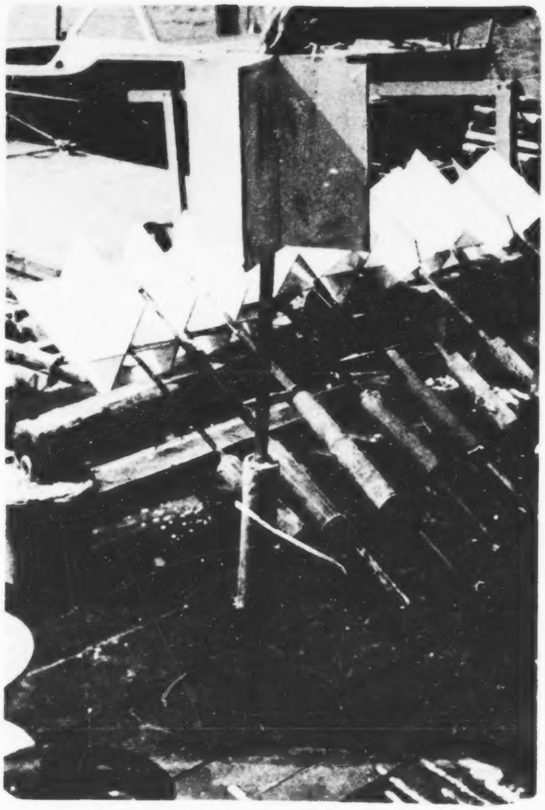


Figure 5-30. Underwater markers used for positioning the submarine on the bottom at the Cox Ledge Station.

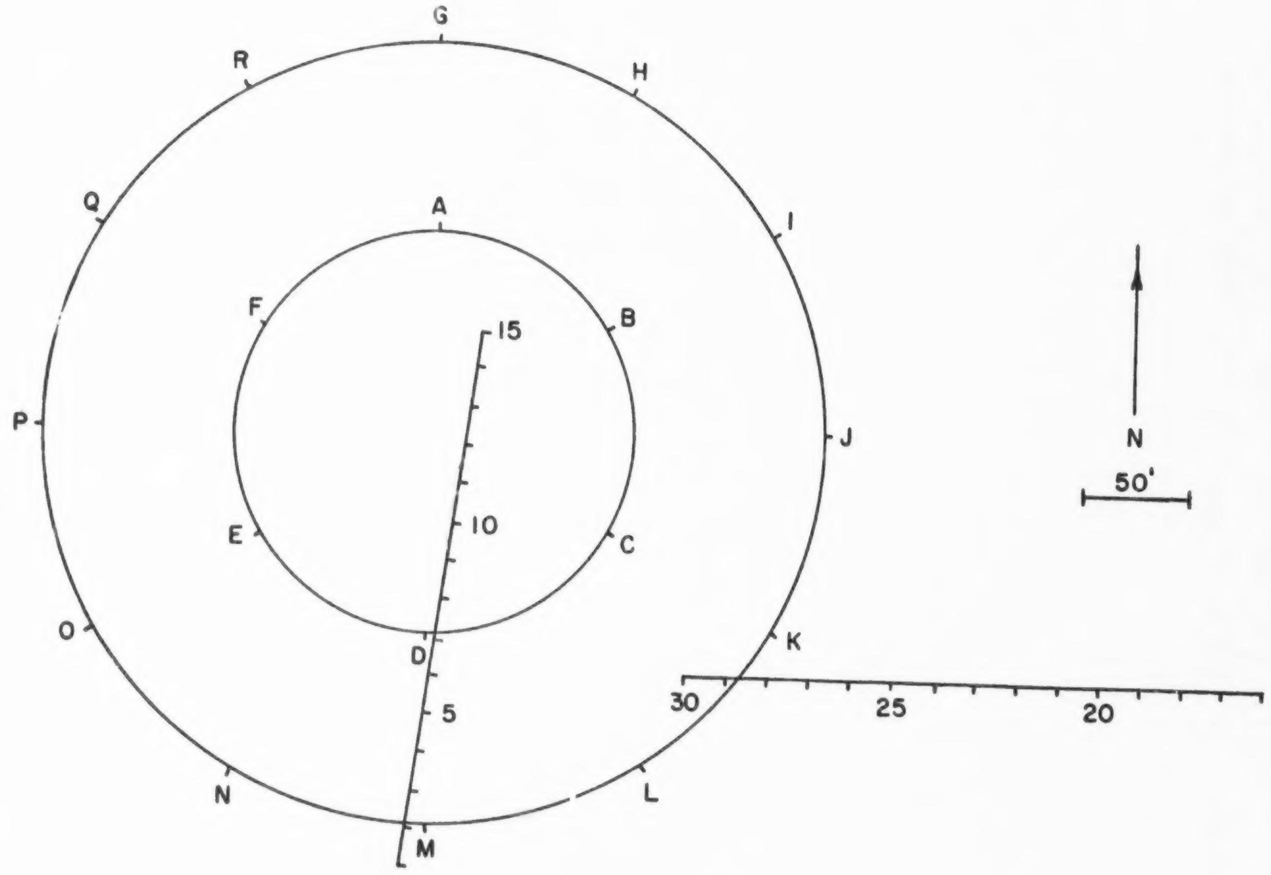

G
R
H
Q
A
I
F
B
15
P
J
N
50'
10
E
C
O
K
D
30
25
20
5
N
L
M

Figure 5-31. Chart of positions of underwater markers at the Cox Ledge Station, July, 1968.

The Dumps

Cans and bottles of various shapes and sizes were used to simulate incinerator residue. Four different dumps were made to minimize the influence of inevitable accidents. Fold-open wire baskets of 2.54 cm plastic mesh and 1.22 M on a side were constructed with an open top (Figure 5-32). **The baskets were** lowered on a bridle attached to a double rope so that when the baskets hit the bottom they would fold out into a 3.66 M cross on **the bottom (Figure 5-33).** This cross would then serve as a reference point of origin.

Three baskets were filled with cans. All three should have been replicates. However, the north dump contained a double batch of small cans and the west dump contained only large cans. Lines fouled during the north dump so that this basket remained half closed. Many of the cans of the west dump failed to sink with the basket and floated off in a southwest direction and sank at random outside of the experimental area. The east dump and the south dump were dropped perfectly. The dumps as they landed contained the following:

1. North Dump	133 420 cm^3 cans	Round 1-22 and A1-A22 Flat 23-44 and A23-A44 Bent 46-67 and A46-A67
	133 1.9 l cans	1/3 each of flat, round and bent
2. East Dump	66 420 cm^3 cans	Round F1-F22 Flat F23-F44 Bent F46-F67
	133 1.9 l cans	1/3 each of flat, round and bent
3. South Dump	360 partially broken bottles	120 each of [illegible] cm^3, 48 cm^3 and 1.1 l size

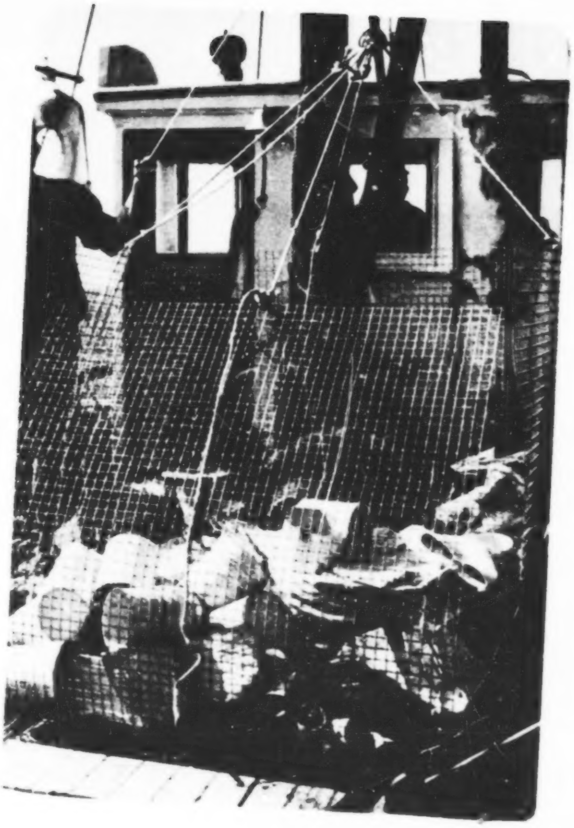


Figure 5-32. The east basket and cans, just before being lowered to the bottom at the Cox Ledge Station.

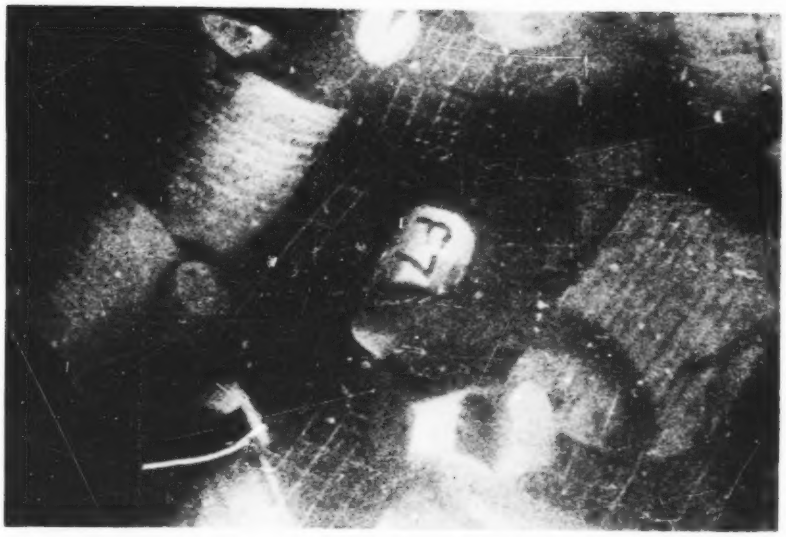


Figure 5-33. A view of the east basket on the bottom at the experimental dumpsite during the second survey.

4.	West Dump	133 1.9 l cans	1/3 each of flat, round and bent

All cans were painted with white road paint and all small cans were numbered. The cans were donated by the American Can Company in Needham, Massachusetts. The bottles were donated by the Coca Cola Bottling Company in Peacedale, Rhode Island.

First Submarine Survey, June 17-19, 1968

A grid search pattern on the bottom proved satisfactory on cardinal headings. Speed was difficult to estimate because of stop and go movement, but about 30 M per minute seemed to be a close estimate. Although visibility was limited to 1-2 M, orientation was good as long as current was slight on the bottom. North-south or east-west tracks were spaced at the turning radius of the submarine (about 6 M). Information from the surface on the position of the tether informed the submarine crew when the submarine had gotten out of the buoyed area.

Tracking the submarine tether from the surface by horizontal sextant angles on the station buoys was not satisfactory. Keeping the tow boat close to the tether proved difficult. Engine noise interfered with submarine communications and surface currents caused the boat to keep drifting away. The location of the baskets was mapped by a quick estimate of the tether in relation to the station buoys (Figure 5-31).

Three of the four baskets were observed from the submarine. Two sides of the north basket were folded over the mound of cans which could then only spill out in the two remaining directions. Few cans extended beyond the area of the basket. The east basket had opened perfectly and the cans formed a symmetrical mound over the center of the cross. The south basket had also opened perfectly.

A few 35 mm pictures were taken through the bottom porthole. However, the field of view was so small that one large can almost obscured the field.

Second Submarine Survey, July 31-August 4, 1968.

The surface tow-boat fixed the position of the submarine on the bottom by running courses and times at constant rpm's from the south and east station markers to the submarine tether buoy. Whenever the observer in the submarine found an important object, communications were made to the surface to take a fix. Mapping inaccuracies were caused by steering errors, surface currents, variable rpm's and scope of the submarine tether line. Thus, considerable variability in position was encountered (Figure 5-34).

Visibility on the bottom was approximately 3 M and conditions for photography were improved over the last survey. At the north dump, the basket and lines were tangled over the cans (Figures 5-35, 5-36). At the east dump an eel pout (*Marcrozoarces americanus*) was observed adjacent to round can F7. The track made by the ballast weight of the submarine was about 10 cm wide and 7 cm deep Figure 5-37). Bottom markers proved useful in determining the position of the submarine on the bottom.

The objects had not moved during the period of time from the first survey. Even the submarine tracks from the first survey were still faintly visible on the bottom. All four dumps

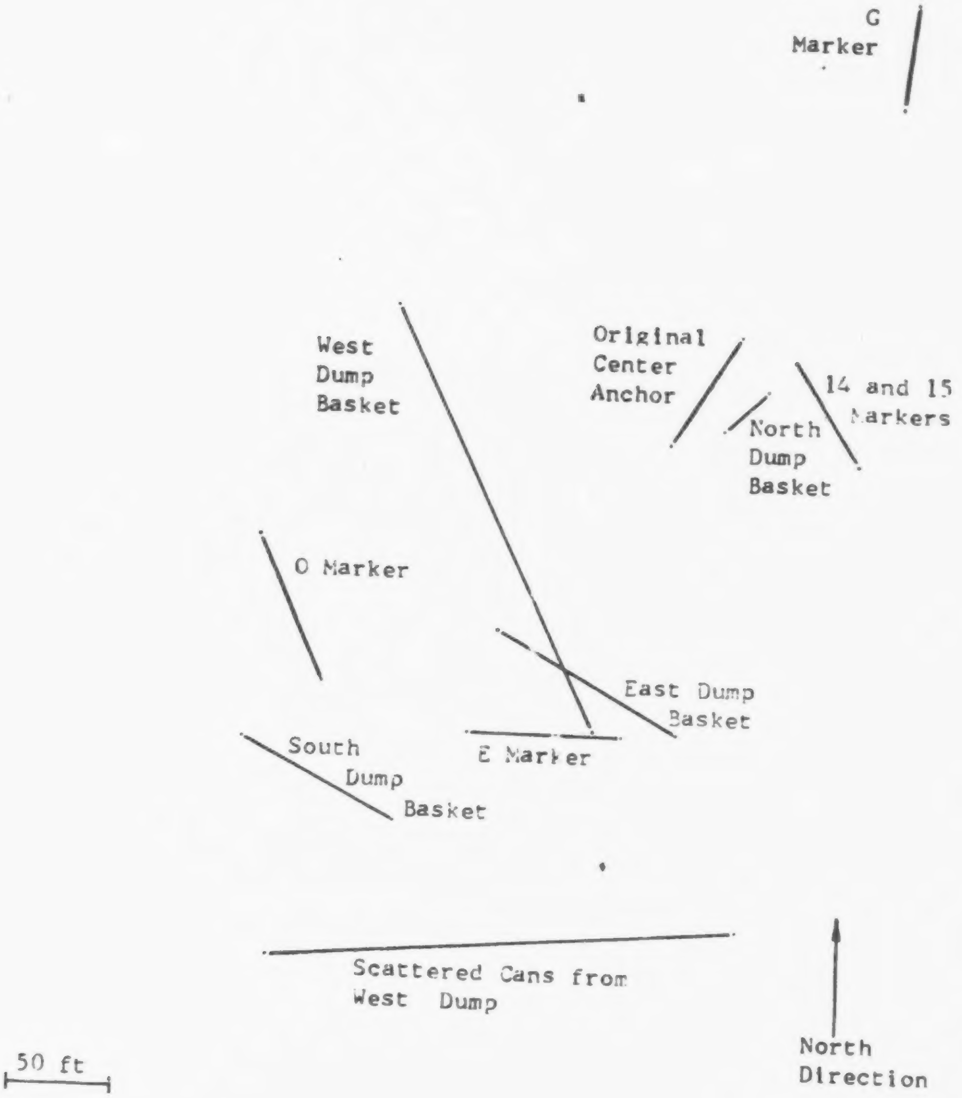

G
Marker
West
Dump
Basket
Original
Center
Anchor
North
Dump
Basket
14 and 15
Markers
O Marker
East Dump
Basket
South
Dump
Basket
E Marker
Scattered Cans from
West Dump
50 ft
North
Direction

Figure 5-34. Chart of objects found on the bottom at the experimental site at the Cox Ledge Station during the second survey, August 1968. Straight lines indicate the variability in position of the object resulting from the mapping procedure.

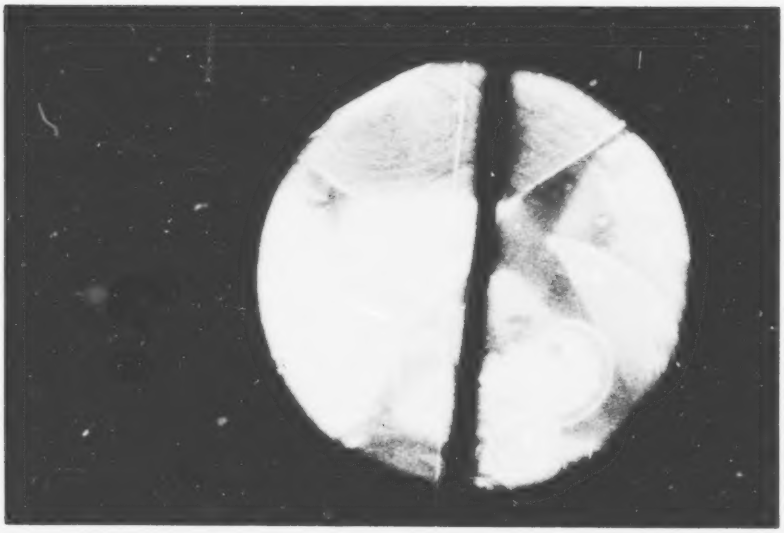


Figure 5-35. Second survey. A view of the North dump through the bottom porthole of the submarine.

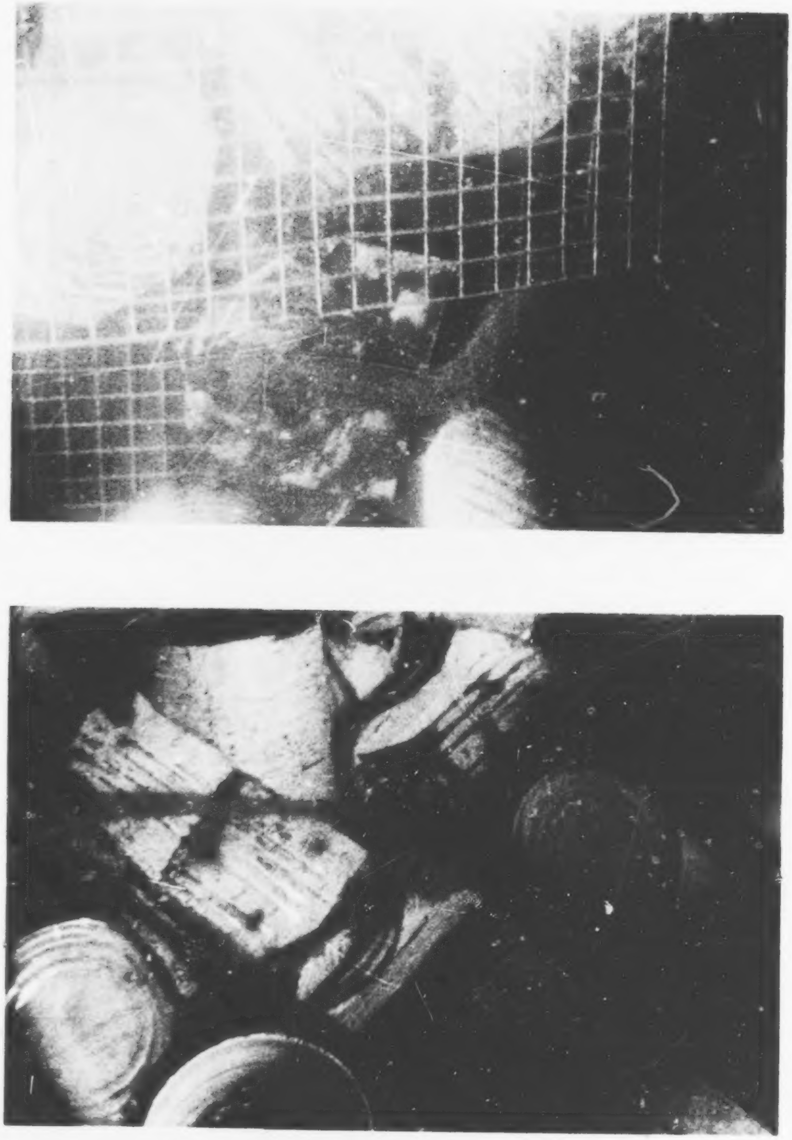


Figure 5-36. Second survey. Two views of the North dump through a side porthole of the submarine.

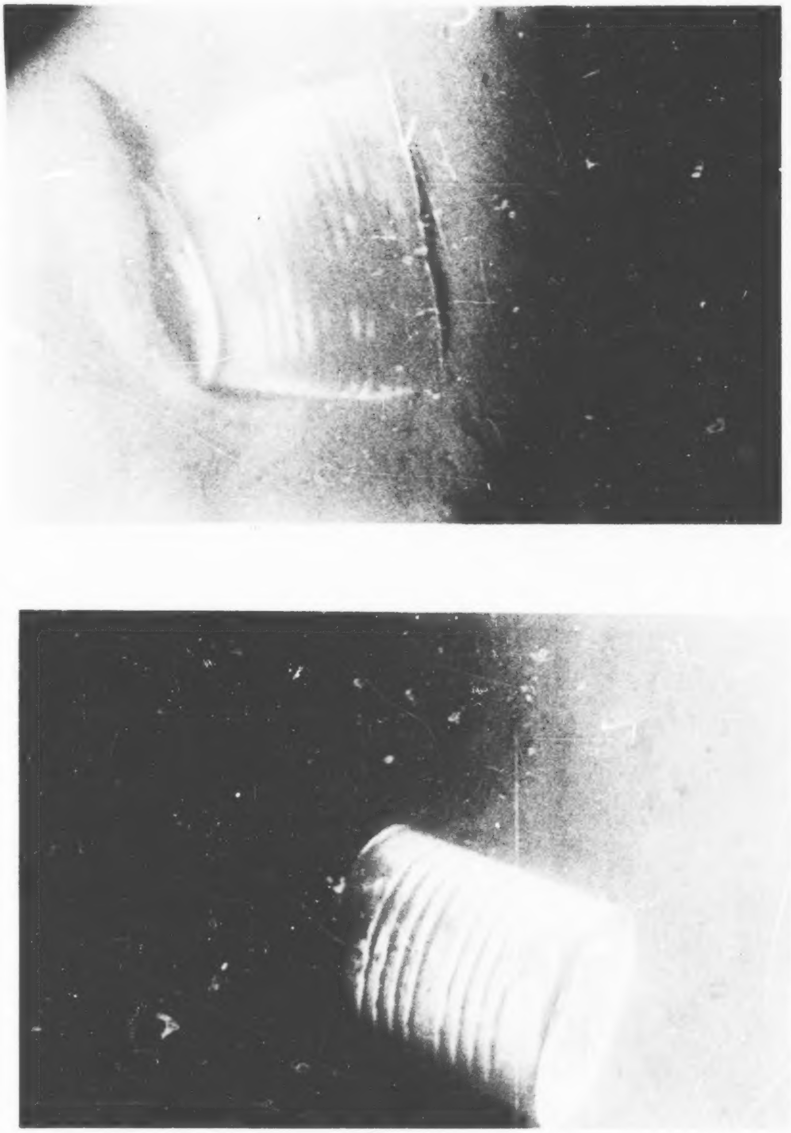


Figure 5-37. Second survey. A round 1.9 l (half gallon) can and a half crushed can from the west dump lying adjacent to the tracks made by the submarine's ballast weight.

were observed and the objects were found no further from their baskets than the initial dropping had placed them. Many of the cans and bottles had fish and even an occasional small lobster in them. One incident during the survey should be noted. An attempt was made to grapple an instrument lost over the side of the vessel. During this attempt the west basket was accidentally brought to the surface, thus eliminating it from the experiment.

Third Submarine Survey, September 4-8, 1968

Another rough chart was made of the location of the dump using the surface tow-boat to fix the position of the submarine tether. (Figure 5-38). Due to errors already mentioned, there was only rough agreement with the last map. Fairly strong surface currents to the west and southwest were probably the main cause of variance.

The positions of objects appeared unchanged. Photographs of all four dumps were taken (Figures 5-39 - 5-42). Submarine tracks from previous surveys were not visible. All dumps were populated by fish and crustacea.

Fourth Submarine Survey, October 21-November 1, 1968

During the first day, the objects were not located. However, ripples were observed with their long axis in an east-west direction and for the first time a fairly strong northeast current was encountered on the bottom. During the second underwater day, all the dumps were located and observed. Mapping of the

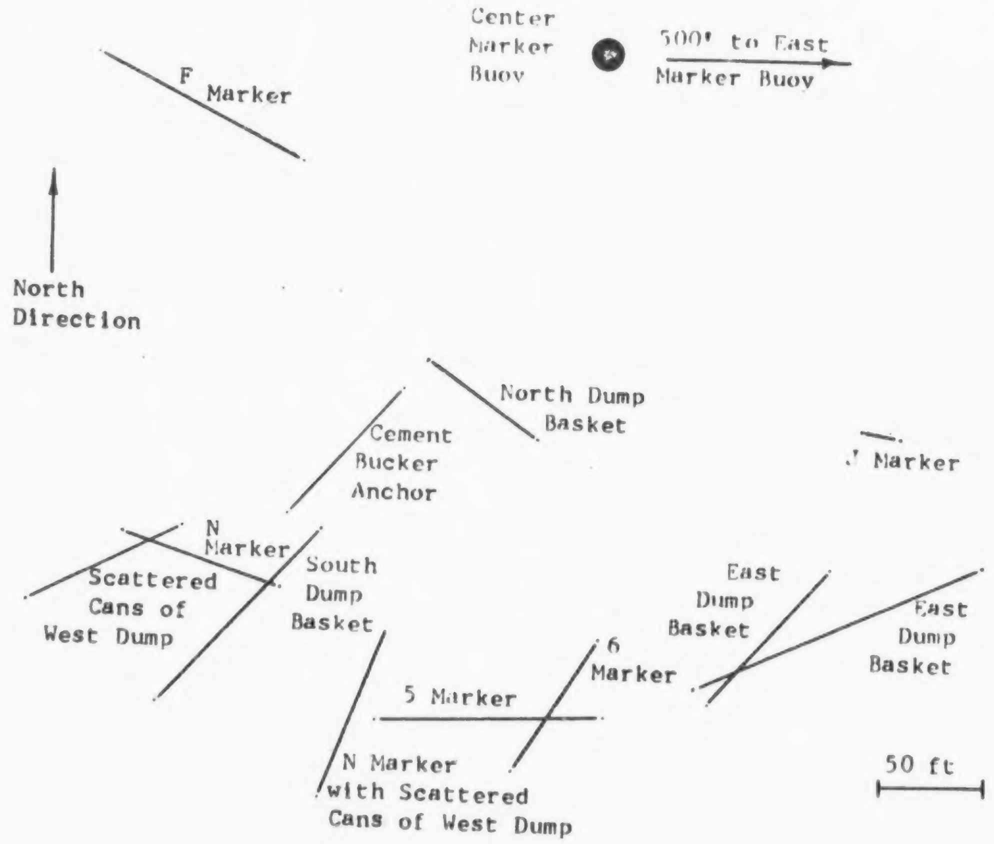

Center
Marker
Buoy
500' to East
Marker Buoy
F Marker
North
Direction
North Dump
Basket
Cement
Bucker
Anchor
J Marker
N
Marker
Scattered
Cans of
West Dump
South
Dump
Basket
East
Dump
Basket
East
Dump
Basket
6
Marker
5 Marker
N Marker
with Scattered
Cans of West Dump
50 ft

Figure 5-38. Chart of objects found on the bottom at the experimental site at the Cox Ledge Station during the third survey, September 1968.

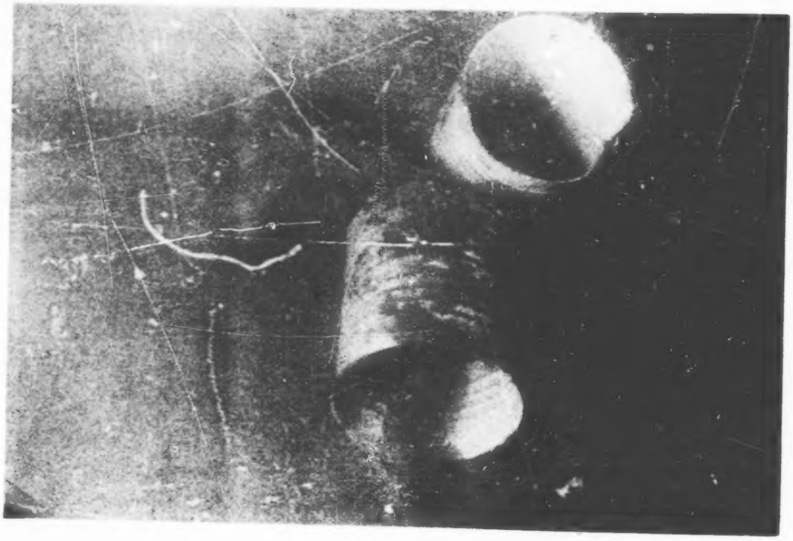


Figure 5-39. Third survey. Round 1.9 l (half-gallon) cans from the West dump.

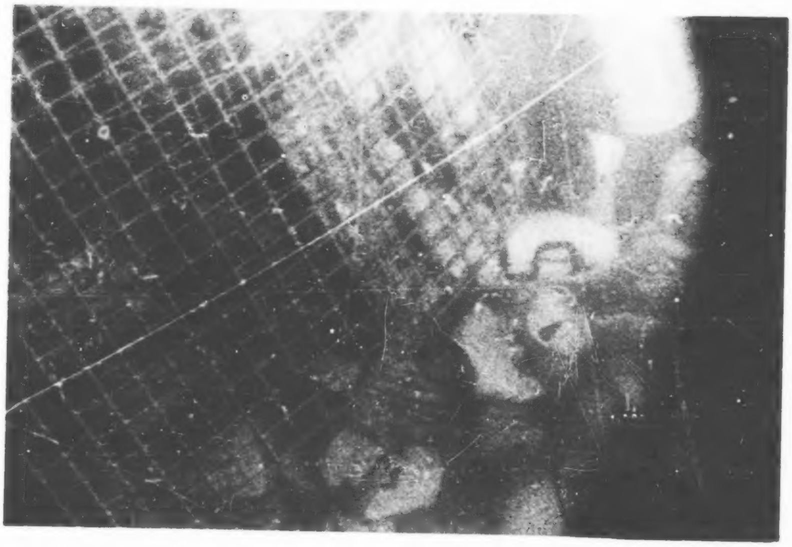
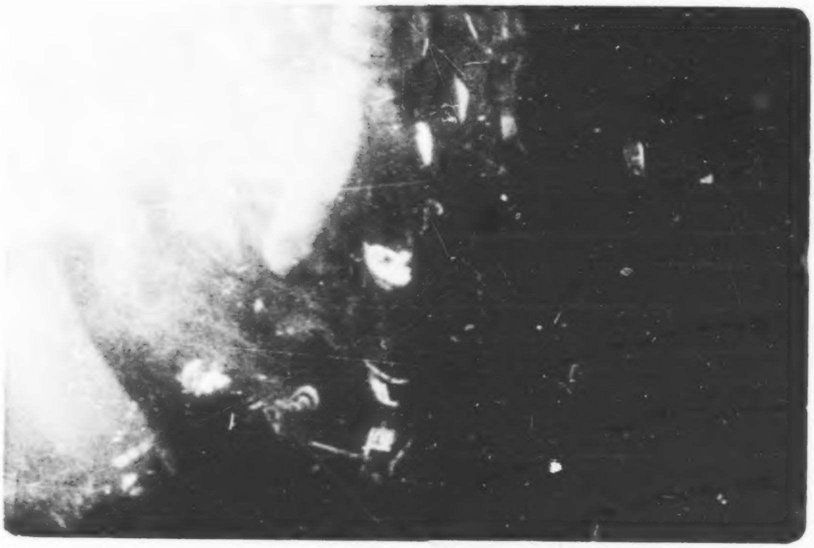


Figure 5-40. Third survey. A view of the North dump showing two sides of the basket closed over the cans.

Figure 5-41. Third survey. A view of the North dump showing an opened portion of the basekt.



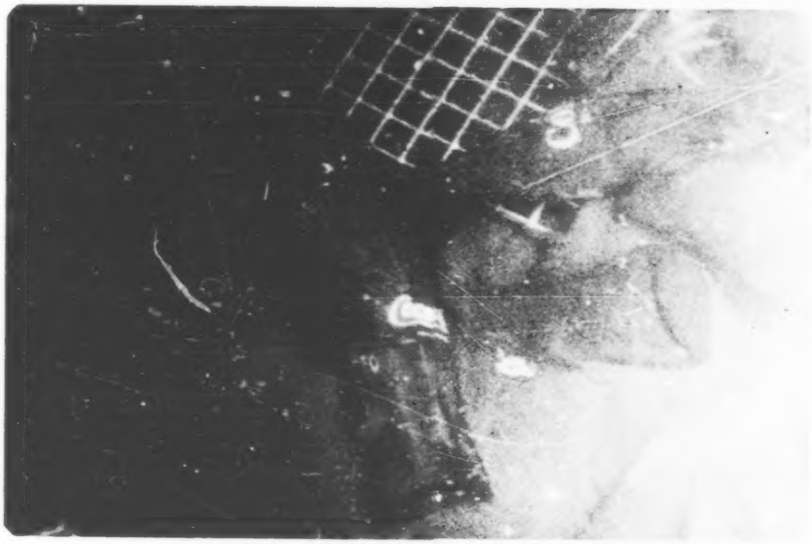


Figure 5-42. Third survey. Two views of the South dump through the portholes of the submarine.

location of the dumps was accomplished in two ways. The surface vessel took compass bearings and measured distance to the submarine tether buoy by radar from the toroid buoy (Figure 5-43). In addition, times and courses for each run were recorded in the submarine and from these data a map was also derived.

Some movement had apparently occurred. Some cans from the north dump appeared to have been shifted off to the southwest direction by several feet (Figure 5-44). Most of the cans, however, were still tangled in the basket (Figure 5-45). Cans from the east basket were bunched across the center of the opened basket and scattered off in a southwest direction (Figures 5-46, 5-47, 5-48). Some of the cans from this basket were located at marker L and according to the numerous mapping attempts, marker L was 12 M-15 M south of the position of the basket. The bottles also appeared to have moved slightly. They no longer formed a symmetrical mound over the basket but had been bunched in the center and were strewn about the center and displaced in the corners of the cross (Figure 5-49). A few bottles had been scattered about 2 M to the southwest. Rusting cans from the west dump were located several times lying unburied on the surface of the bottom.

Observations on which shape of can moved farthest were very limited. Round large cans from the east dump were found furthest from the point of origin, a bent large can was found just before the east dump basket was located and most of the flattened large cans appeared to be still on the basket. However, the reverse was suggested when the numbers for the small cans still remaining on the basket were recorded. Thirteen round, 5 bent and 4 flat cans were found. Probably these numbers are more indicative

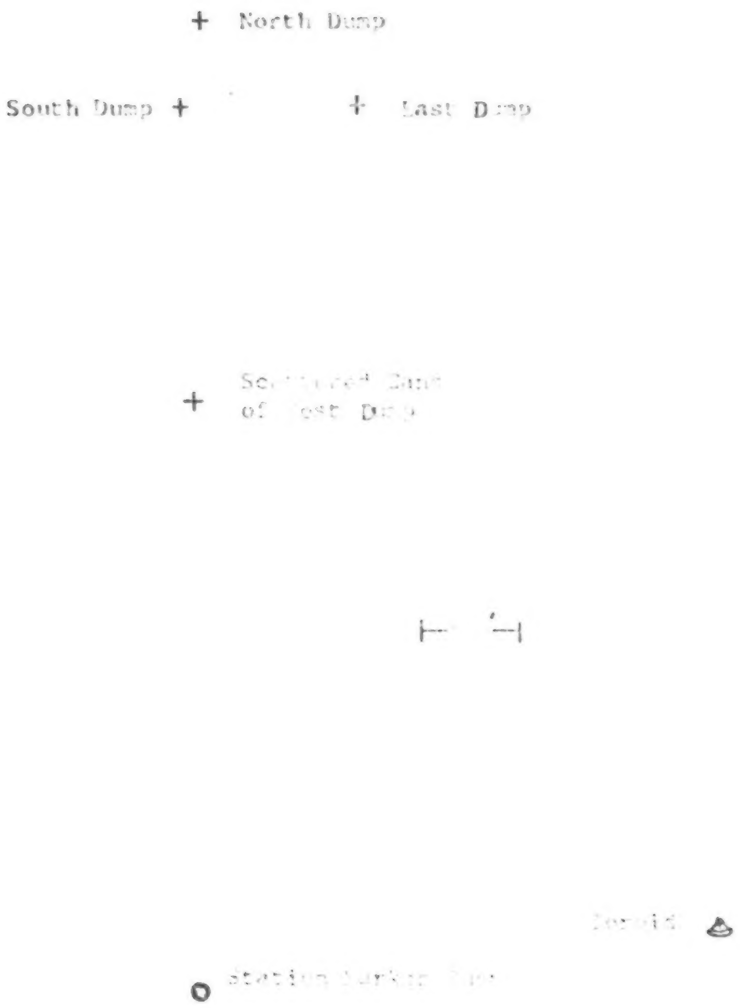

North Dump
South Dump
East Dump
Scattered Sand
of West Dump
[illegible]
Station Marker Buoy

Figure 5-43. Chart of the experimental site at the Cox Ledge Station during the fourth survey as mapped by the Billie II, November, 1968.

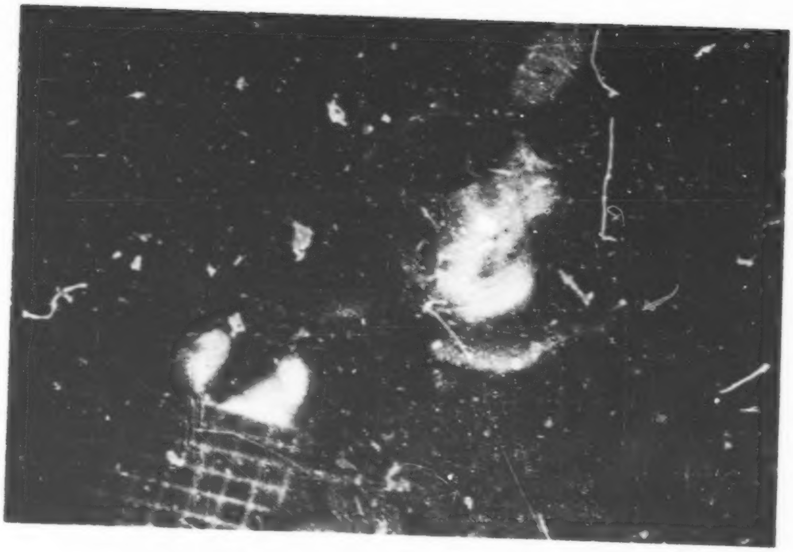


Figure 5-44. Fourth survey. A view of the North dump showing cans which have moved off the Southwest side of the basket. Note the fish (eel pout) in the center of the picture.

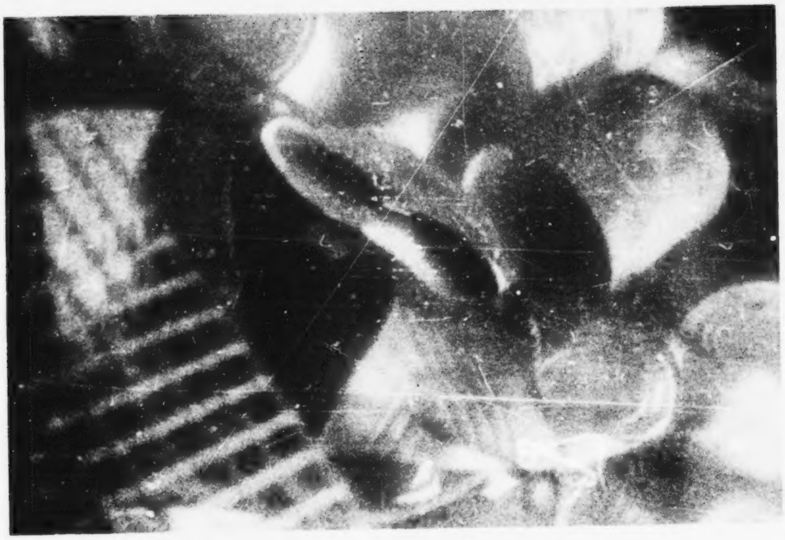


Figure 5-45. Fourth survey. A view of the North dump showing two sides of the basket still closed over the cans.

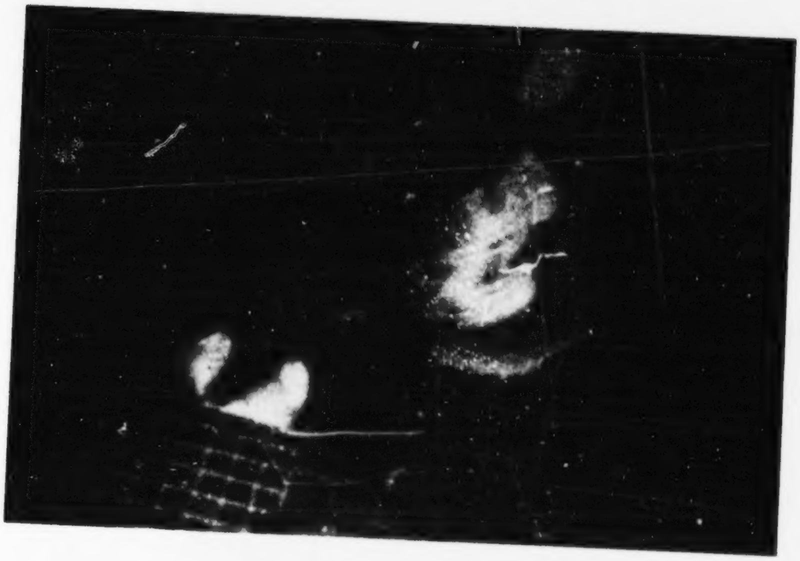


Figure 5-44. Fourth survey. A view of the North dump showing cans which have moved off the Southwest side of the basket. Note the fish (eel pout) in the center of the picture.

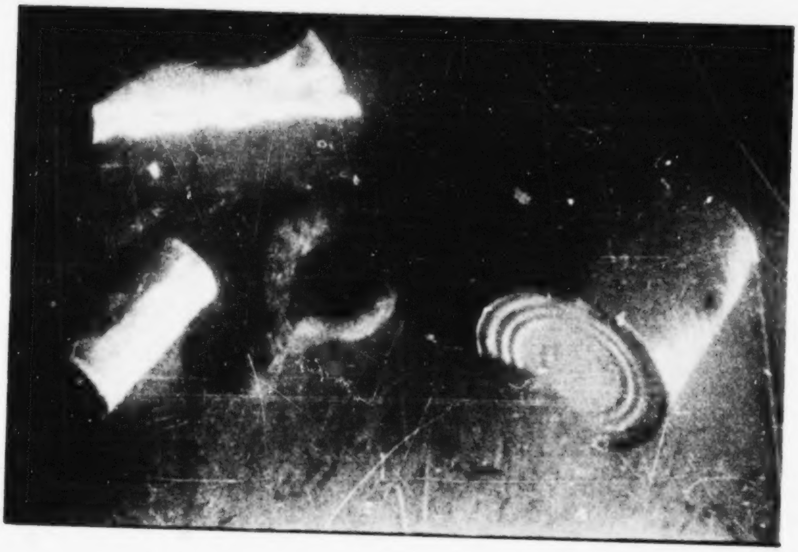


Figure 5-46. Fourth survey. A view of the East dump showing cans which have moved off the side of the basket. Note the fish (eel pout) in the center of the picture.

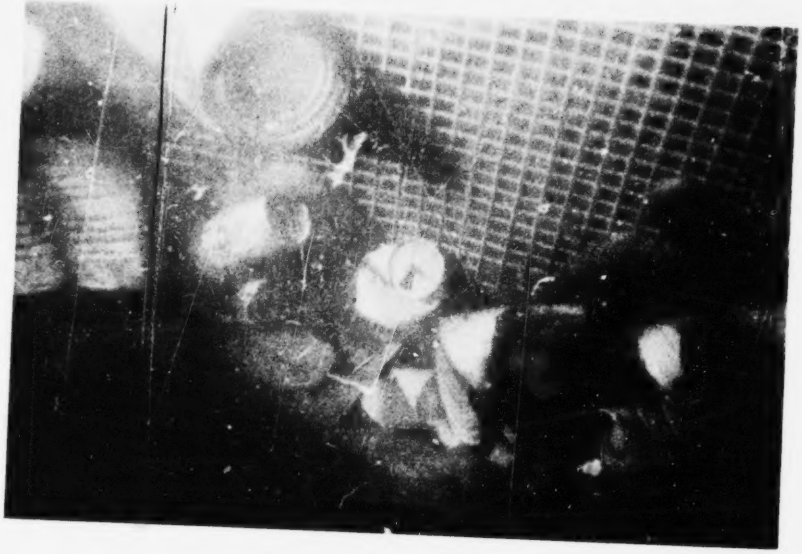


Figure 5-47. Fourth survey. A view of the East dump showing cans which have been cleared to form a row across the center of the basket (See figure 22).

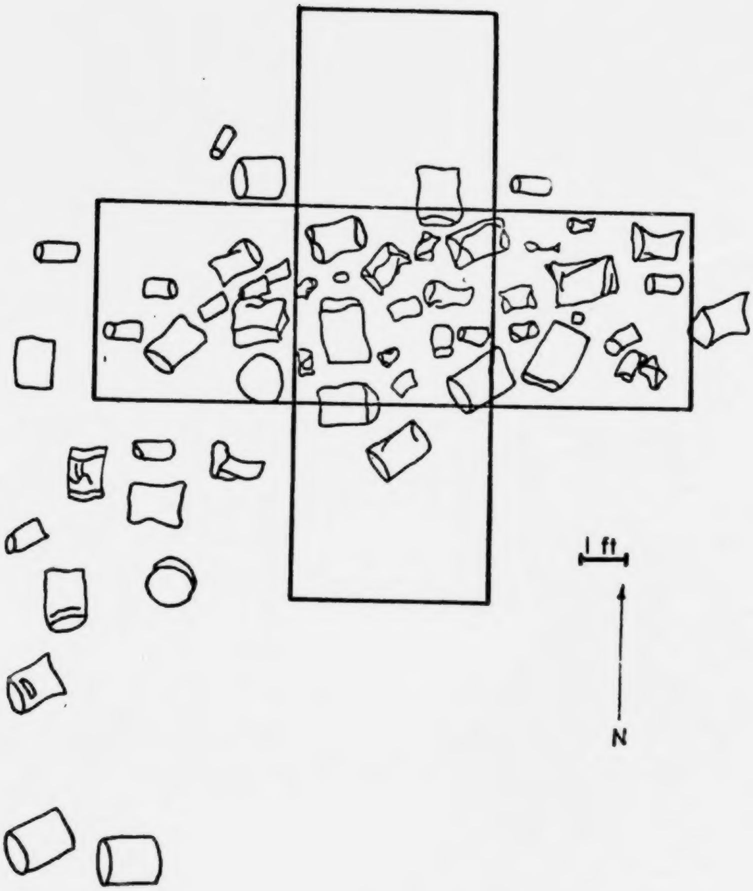


Figure 5-48. A sketch of the approximate distributions of cans over the East basket. No attempt was made to represent the number of cans accurately.

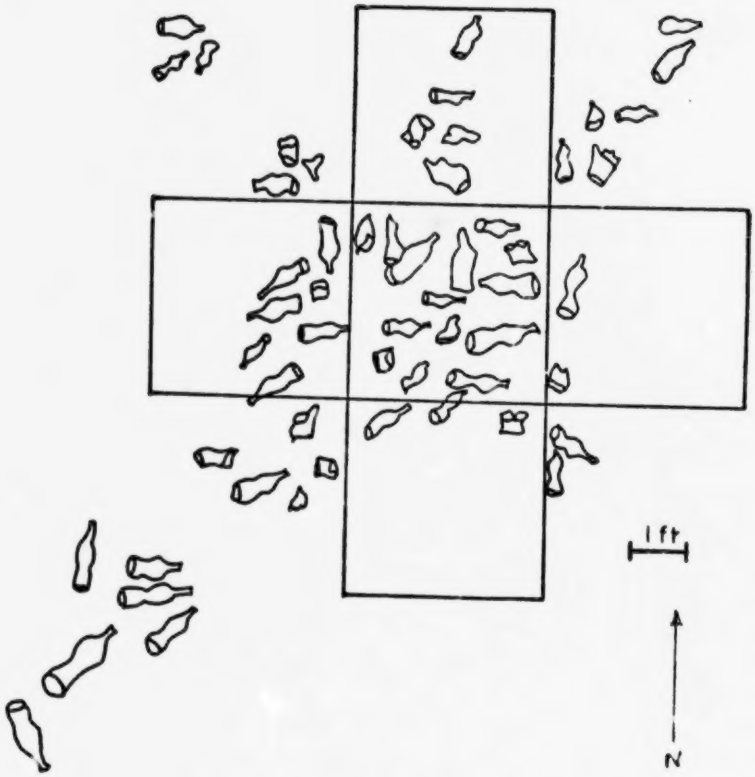


Figure 5-49. A sketch of the approximate limits of distribution of bottles over the South basket. No attempt was made to represent the number of bottles accurately.

of the greater visibility of the round cans rather than an indication of their lack of movement.

SECTION 6

EVALUATION OF AN OCEAN BASED SOLID WASTE DISPOSAL SYSTEM: AIR POLLUTION CONTROL ASPECTS

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6-1

EVALUATION OF AN OCEAN BASED SOLID WASTE DISPOSAL SYSTEM: AIR POLLUTION CONTROL ASPECTS

James R. Mahoney

I. Introduction

This report evaluates the possibility that off-shore incineration might lead to adverse air quality along the coastline when an on-shore wind occurs locally.

The meteorological research has been designed to answer the following three questions:

(1) What are the atmospheric transport patterns which bring contaminant material back toward populated areas from the proposed off-shore burning operations? Answers to this question directly influence operational decisions for the proposed system; e.g., when a steady off-shore wind occurs locally, incineration can be carried out safely at or near the shore but during on-shore winds, incineration must be delayed until the ship is a safe distance from the shore. As the rate of turbulent mixing in the lower atmosphere over the ocean is normally significantly less

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than the rate over land, direct measurements in the atmosphere over the ocean must be used to evaluate mixing rates.

(2) How are daily and seasonal air pollution concentrations related to prevailing weather conditions? An ocean based incineration system would be especially effective for preventing air pollution whenever pollutant concentrations in the local metropolitan area were high and it might be possible to use the ocean system exclusively during acute air pollution episodes.

(3) What are the frequency and persistence of severe weather conditions which would retard or prevent the operation of an ocean disposal system for safety reasons? Safety criteria depend to some extent upon the choice of disposal vessel. If a self-propelled incinerator ship is used, it can operate without interruption during most of the year and only a small number of weather cancellations can be expected during the winter months along the northeastern coast of the United States. If a towed vessel is used, more frequent delays can be expected during periods of strong winds. In either case, should infrequent but persistent severe weather conditions cause a cancellation of ocean disposal operations for several successive days, serious disposal dislocations could result unless emergency landfill sites have been reserved for this purpose.

Answers to these questions are presented in Section II, which describes the marine meteorological research carried out to evaluate transport properties for the near-shore marine atmosphere (the principal topic of this study), Section III, which presents estimated shoreline concentrations of contaminants during adverse conditions, Section IV, which contains a review of climatological data pertaining to operational safety for an ocean based system, and Section V, which summarizes background air contaminant observations carried out at the School of Public Health during the study period. A general summary, discussion, and conclusions appear in the final section.

II. Measurements of Atmospheric Turbulence in Boston Harbor

A. Introduction

To estimate the rate of atmospheric dispersion from an ocean based incinerator, it is necessary to know the turbulent properties of the atmosphere immediately above the ocean and how these properties change as the weather changes. In addition, one must know the relationship between meteorological conditions observed at coastal weather stations and conditions found in the first twenty miles off shore. Observations reported here provide information for each of these categories.

B. The Limiting Meteorological Condition: Steady, On-Shore Sea Breezes

The on-shore daytime sea breeze observed at coastal locations during the summer and autumn seasons at mid-latitudes is the weather pattern which could most restrict near-shore operation of an incinerator ship. The sea breeze is a steady wind which arises because of the thermal differences between a land area which is warmed on a sunny day and an ocean area which exhibits very little daily temperature variation. Typical surface wind speed associated with sea breeze circulation is 5 meters/sec and turbulence intensity within the sea breeze is usually very low because it arises over the ocean, which represents a much smoother boundary for the atmosphere than most land areas, and because the ocean surface represents a heat sink for the summer daytime atmosphere in mid-latitudes. Therefore, the lowest part of the local atmosphere is stable and the increased stability inhibits the development of turbulence.

Most published field and theoretical studies of sea breeze phenomena have been concerned with the sea breeze after it has entered the coastal land area. An extensive study of sea breezes over land areas was carried out in 1922 by van Bemmelen, who described the land breeze (an off-shore wind) found one to two kilometers above the on-shore sea breeze during the daytime. This and other early observations have been summarized by Defant (1951). More recently, sea breeze phenomena have been reported for the New York City area (Frizzola and Fisher, 1963), and the California area surrounding San Francisco (Frenzel, 1962; Fosberg and Schroeder, 1966). These studies indicate that the influence of a sea breeze may be felt as far as 50 kilometers inland and even further when unusually well developed.

In a theoretical study of sea breeze described by Haurwitz (1947), the sea breeze was considered a direct thermal circulation modified by turbulence introduced at the lower boundary (particularly over land), the rotation of the earth, and the prevailing synoptic weather pattern. Later studies by Estoque (1961, 1962) introduced the use of numerical model calculations to sea breeze studies which have exhibited good agreement with observed data.

Van der Hoven (1967) summarized the results of two experimental programs, one in Chesapeake Bay and the other in Long Island Sound, which discriminate between overland and overwater properties of coastal winds. In both studies, the data were collected at coastal locations and the mean wind direction data were used to identify the history of the sampled winds during each field measurement. Van der Hoven estimated that overwater diffusion rates were less by a factor of three than overland diffusion rates.

The experimental program described here was designed to provide information about the summer and autumn sea breeze structure in the Boston harbor area.

C. Experimental Program

Atmospheric turbulence was observed during summer and autumn of 1966 and 1967 in Boston Harbor to determine atmospheric diffusion rates over the ocean and other meteorological observations were made to aid in the analysis and extrapolation of the data.

Observations were made on board the Research Vessel Shrock, a diesel powered vessel, 15 meters in length, owned by the Department of Geology and Geophysics at the Massachusetts Institute of Technology. We equipped the Shrock with two bivane anemometers and two fine wire thermocouples mounted on a boom extending off the bow of the ship and an extension of the main mast for the measurement of wind and atmospheric temperature. A third thermocouple recorded ocean water temperature at a depth of approximately one meter. An Eppley pyrheliometer, sensitive to direct and diffuse solar radiation, was also used.

The bivane anemometers (Vectorvanes, Meteorology Research, Inc.) have a starting threshold of 0.25 meters/sec and a response distance of approximately one meter. These characteristics are well suited to shipboard turbulence observations as high frequency motions (e.g., those greater than 1 cps) cannot be measured satisfactorily because of the motion of the ship. The bow anemometer was approximately 3 meters above the ocean water surface and about 2.5 meters forward of the ship. The mast anemometer was approximately 11 meters above the water surface at a mid-ship location. These positions were chosen to provide the greatest possible vertical separation of the instruments and least interference by the mass of the vessel.

The fine wire thermocouples used to monitor air temperature employ copper-constantan junctions and have a response time of approximately one quarter second. A thermocouple was mounted adjacent to each of the anemometers. A heavy duty thermocouple (also copper-constantan) used to measure water temperature has a response time in water of approximately one half second.

Figure 6-1 shows the Shrock and the instruments.

Most of the observations were obtained at five stations in Massachusetts Bay along a line perpendicular to the local coastline. To save navigation time during periods of reduced visibility because of haze and fog the stations were located at permanent marker buoys. **Figure 6-2** contains an outline of Massachusetts Bay and shows the five stations numbered 0 through 4. Station 0, a baseline station, is about 200 meters from the waterfront shoreline in the Boston Inner Harbor. Highest levels of atmospheric turbulence were expected here (and were observed) because local air flow is strongly influenced by nearby built-up areas of the city. Station 1, in open water, is relatively well protected from the wind and waves frequently encountered at the outer stations, particularly station 4. Exposure to open sea conditions increases from station 0 to station 4.

Figure
6-1

A view of the Research Vessel Schrock
with anemometers mounted forward of
the bow and on top of the mast.

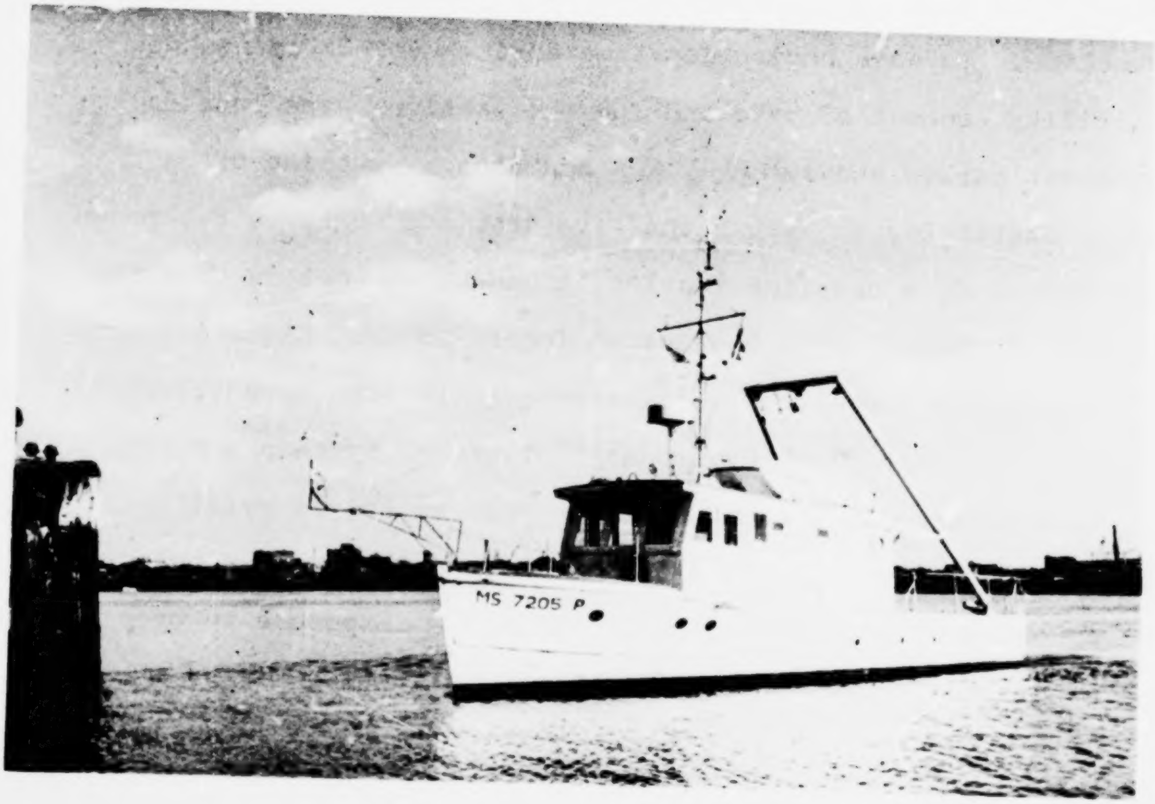
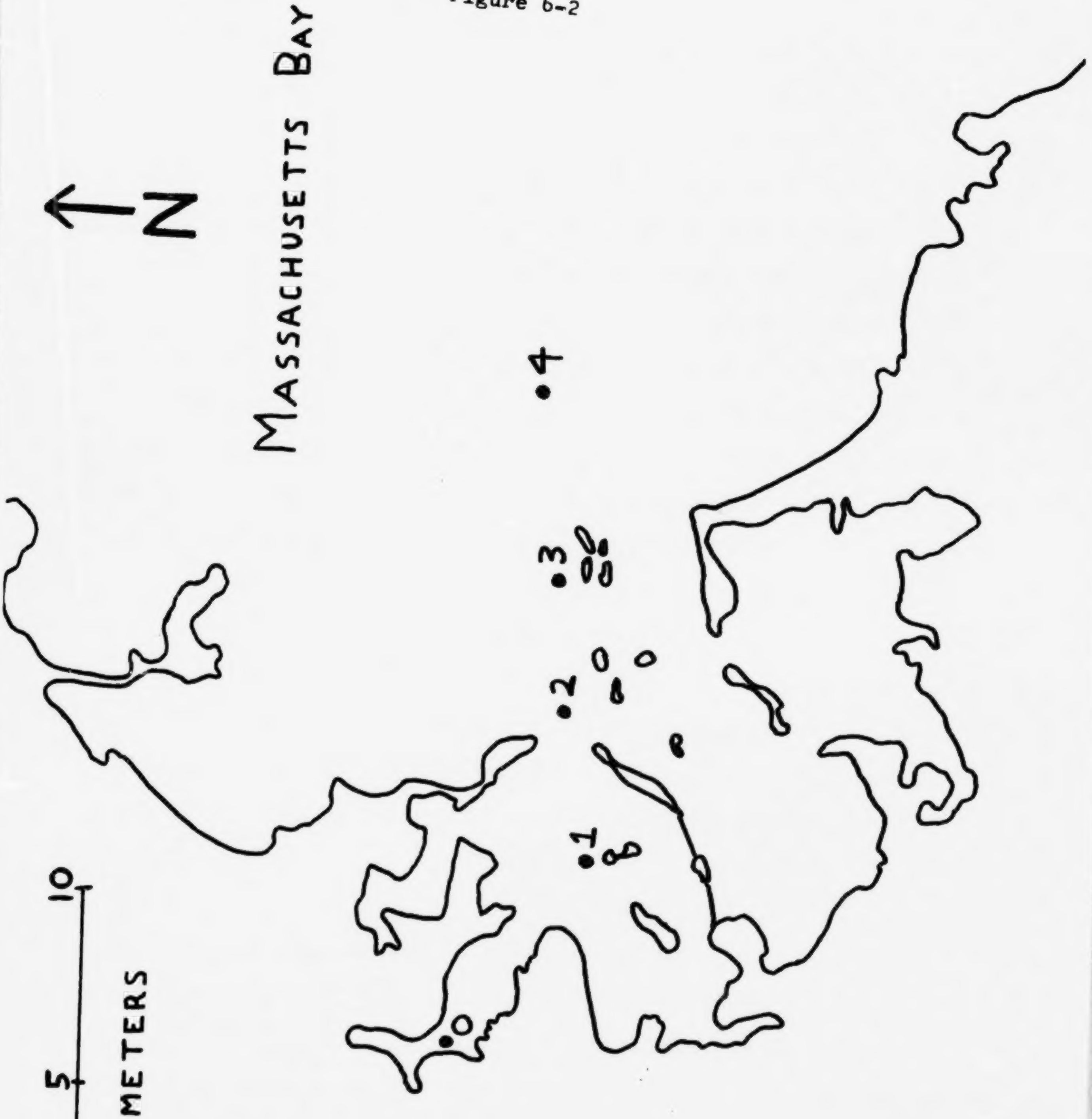


Figure 6-2


MASSACHUSETTS BAY
N
KILOMETERS
0
5
10
0
1
2
3
4

Map of the Massachusetts Bay region showing the location of the sampling stations used in the study.

With few exceptions, measurements were made for periods of 20 minutes to provide an adequate length of record to assure representativeness in the atmospheric turbulence data, but short enough to allow completion of several stations within a reasonable working time.

The bow and mast anemometers were mounted so that the 180° azimuth direction corresponded to the ship's centerline direction. Continuous records of wind speed, azimuth angle, and elevation angle were obtained from both instruments during 20 minute observation periods and the ship's heading was recorded from the ship's compass once each 30 seconds. Air temperature (two thermocouples), water temperature, and solar radiation were recorded simultaneously with approximately 75% of the total recording time employed for the air temperature data. Water temperature was constant at each station during a 20-minute data acquisition period and solar radiation varied only during periods of variable cloudiness. General weather and sea state were also observed and noted.

Table 6-1 is a summary of 44 field observations over 8 days. The "Station Sequence" column in Table 6-1 indicates the order in which data were collected during each observing day for the station numbers identified in Figure 6-2.The "Observation" columns in the table contain an "X" each day the data records are complete or nearly complete.

TABLE 6-1

Summary of Meteorological Observations in Boston Harbor

Date	Station Sequence	Wind Observations		Temperature Observations			Sunshine Observations
		Bow	Mast	Bow	Mast	Water	
8/30/66	1,2,3,4, 1,2,3		X	X	X		X
9/1/66	1,2,3,2	X	X	X	X	X	
9/2/66	1,2,3,4	X	X	X	X	X	X
10/11/66	1,2,3,4,2	X	X	X	X	X	X
10/12/66	1,2,3,1,0	X	X	X	X	X	X
10/19/66	0,1,2,3, 2,1,0	X		X		X	
10/28/66	0,1,2,3, 4,0	X	X	X	X	X	X
7/11/67	0,1,2,3, 4,0	X	X	X		X	X

D. Data Reduction Procedures

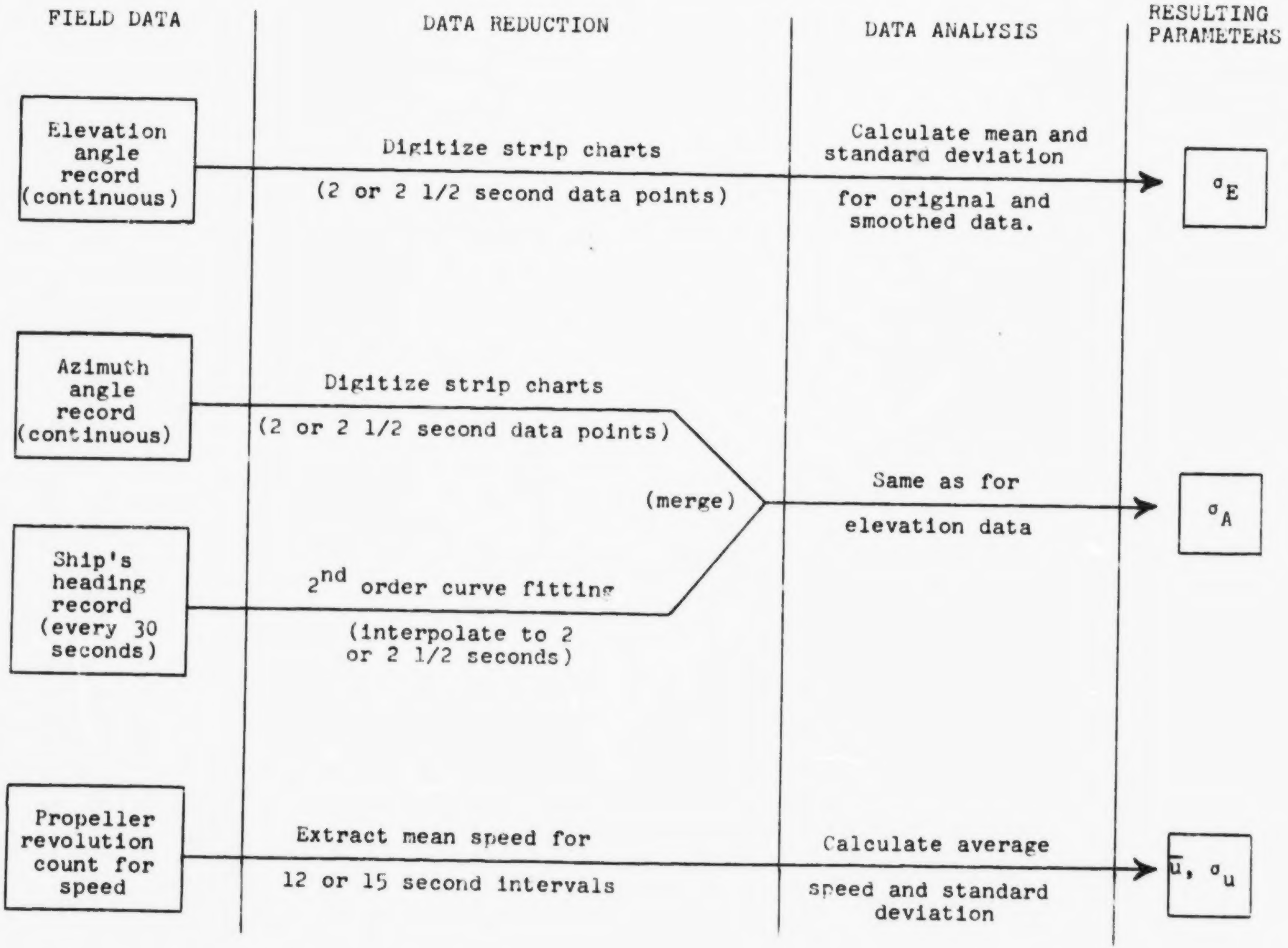
Wind observations were used primarily to evaluate atmospheric turbulence intensity and temperature observations were used to indicate atmospheric stability.

The data collection, reduction, and analysis scheme for the wind observations is summarized in Figure 6-3.The field data illustrated in the left column were collected on a three channel recorder (two analog channels and one side marking channel) and the ship's heading, read from the ship's compass, was logged every 30 seconds. Elevation and azimuth angle data were digitized by reading the intersections of the recorded traces with the time divisions marked on the chart paper. One data point was noted each two seconds for approximately half the record and one data point each two and one half seconds for about 25% of the remainder. Ten second average values were obtained from the strip charts for the first three observing days. Reduction of strip chart data proved to be tedious and time consuming. Use of multi-channel tape records instead of strip charts results in at least an order of magnitude decrease in data reduction time.

When elevation angle data are available in digital form, they can be processed directly. Means and standard deviations for every data set from each station were calculated and then the original data were subjected to six successive 2^n-type smoothings (i.e., the original 600 two-second data points were averaged in pairs to create 300 four-second points; pairings

Figure 6-3

Data Flow Scheme for Wind Observations


FIELD DATA
DATA REDUCTION
DATA ANALYSIS
RESULTING PARAMETERS
Elevation angle record (continuous)
Digitize strip charts
(2 or 2 1/2 second data points)
Calculate mean and standard deviation
for original and smoothed data.
σ_E
Azimuth angle record (continuous)
Digitize strip charts
(2 or 2 1/2 second data points)
(merge)
Same as for
elevation data
σ_A
Ship's heading record (every 30 seconds)
2^{nd} order curve fitting
(interpolate to 2 or 2 1/2 seconds)
Propeller revolution count for speed
Extract mean speed for
12 or 15 second intervals
Calculate average
speed and standard deviation
$\bar{u}$, σ_u

were repeated five more times to create data sets based upon 8-second, 16-second, 32-second, 64-second and 128-second averages). Standard deviations for each of the smoothed data sets were calculated, also. These results are discussed in the next section.

Azimuth angle data, measured relative to the centerline of the ship, were digitized in the same manner as the elevation angle data. The ship's heading data (available as discrete observations each 30 seconds) were subjected to successive, overlapping, second order interpolations, involving three data points at a time over a one minute interval. (Second order curve fittings were used because changes in the ship's heading usually followed a damped harmonic form.) Most heading changes were less than 10° during the 30-second recording interval.

The "relative azimuth" data were merged with the interpolated ship's heading data to produce a "true azimuth" record equivalent to the elevation record as illustrated in Figure 6-3. Analysis of true azimuth data then proceeded in the same manner as for elevation, i.e., mean values and standard deviations for the basic sampling frequency and for successive smoothings of the data were calculated.

Wind speed data were collected as a series of side marks on moving paper charts with the spacing between marks inversely proportional to speed. A multiplying constant was determined by the pitch of the anemometer propeller, the chart paper speed, and the paper marking rate (i.e., the number of propeller revolutions per mark on the paper). The side mark spacing was measured once for every 15 seconds of chart paper travel, providing 80 data points for each 20-minute observing period. Average wind speed and standard deviation was calculated for each 20-minute period.

E. Analysis of Atmospheric Turbulence Data: Case Studies

A case study method of data analysis was adopted for the five experimental days which produced the most useful data. A general data analysis which incorporates information from other experimental days, as well, is presented after the case studies. Specifically, the relationships between turbulent intensities, meteorological conditions (atmospheric stability and mean wind speed) and surface roughness conditions have been examined and the influence of the ship's motion upon the turbulence data has been investigated.

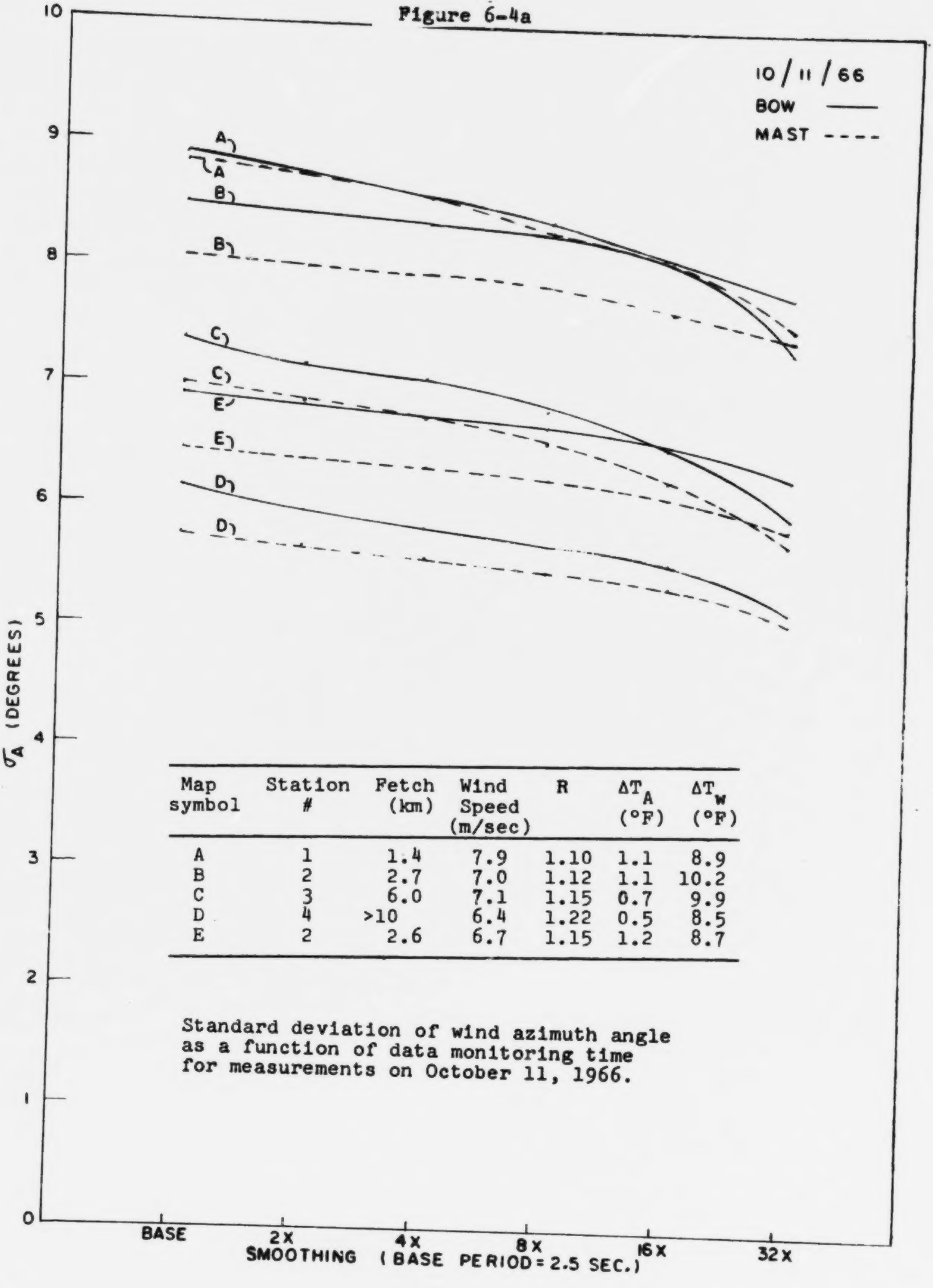
October 11, 1966

This was a typical fair weather autumn day. Daytime temperature varied between 51°F at sunrise to a maximum of 67°F at mid-afternoon. Light to moderate winds from the southwest (i.e., off-shore) occurred throughout the observing period. Wind speed at Logan Airport (Boston) was 13 mph at 10:00 AM (EDT), 16 mph at 1:00 PM, and 10 mph at 4:00 PM. The sky was clear but hazy during the morning but extensive convective cloudiness occurred during the afternoon. Wind speeds were observed to increase as the distance away from shore increased. Although the day was generally sunny, no sea breeze developed. Moderate SW winds and relatively low solar inclination were probably responsible for the absence of direct thermal (sea breeze) circulation.

Figures 6-4a and 6-4b illustrate σ_A and σ_E (wind azimuth and elevation angle fluctuations) for the five observing stations completed during this day. Station numbers correspond to those shown in Figure 6-2. For each station, the standard deviation for the observed wind azimuth (or elevation) angle is shown for the basic sampling periods (2 1/2 seconds) and for the smoothed data up to a maximum of 32-fold smoothing, which corresponds to 80-second average data. Data from both the bow and the mast anemometer systems are shown for each observing station.

Figure 6-4a also contains a listing of other pertinent data concerning the observations. The "fetch" column is a record of the overwater travel path of the wind before reaching the ship's location under the assumption that the wind direction is unchanged. This assumption is imperfect, but it is important to have a measure of the overwater travel length to evaluate the differing effects of boundary-induced mechanical turbulence over land and over water. Wind speed data are average speeds calculated from mast data for a 20-minute observing period. The constant, R, is the ratio of mean mast level to mean bow level wind speed. Generally, vigorous turbulent mixing

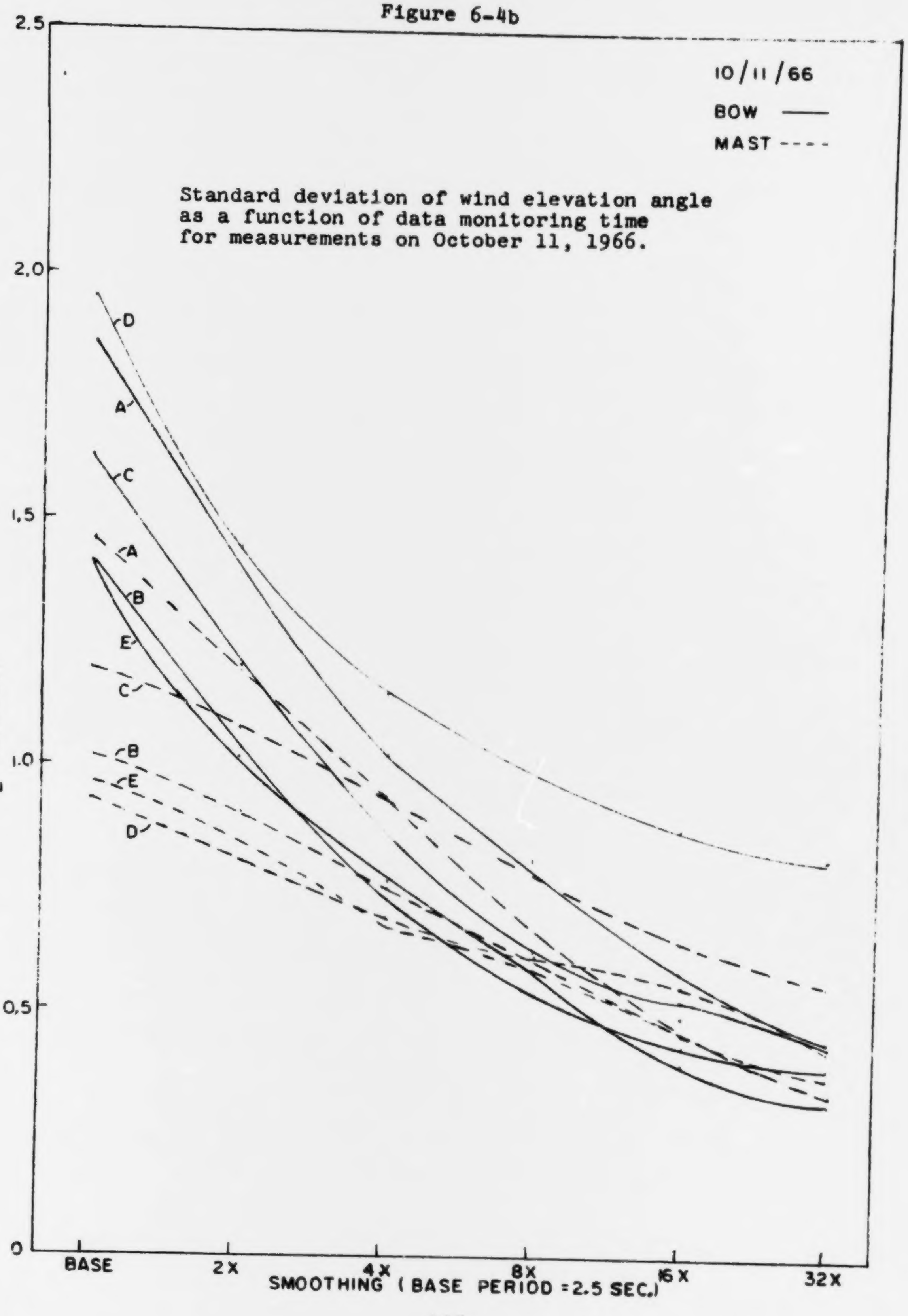
Figure 6-4a



Map symbol	Station #	Fetch (km)	Wind Speed (m/sec)	R	ΔT_A (°F)	ΔT_W (°F)
A	1	1.4	7.9	1.10	1.1	8.9
B	2	2.7	7.0	1.12	1.1	10.2
C	3	6.0	7.1	1.15	0.7	9.9
D	4	>10	6.4	1.22	0.5	8.5
E	2	2.6	6.7	1.15	1.2	8.7

Standard deviation of wind azimuth angle as a function of data monitoring time for measurements on October 11, 1966.

Figure 6-4b



Standard deviation of wind elevation angle as a function of data monitoring time for measurements on October 11, 1966.

throughout the lowest levels of the atmosphere results in $R \approx 1$. During greater stability and more nearly laminar flow at the lowest levels, values of R increase.

The column labeled ΔT_A contains the air temperature difference data ($T_{mast} - T_{bow}$) and the column labeled ΔT_W contains the air-water temperature difference data ($T_{mast} - T_{water}$). Generally, bow temperature will be intermediate between water and mast temperatures but when atmospheric mixing increases, air temperature difference decreases. When water temperature exceeds air temperature, the lowest part of the atmosphere may be unstable. For a vertical separation of 8 meters between mast and bow observing systems, the dry-adiabatic temperature difference is 0.08°K (= 0.14°F); therefore, values of ΔT_A smaller than -0.14°F indicate instability.

The following observations may be noted from Figures 6-4a and 6-4b:

> Bow standard deviations are larger than mast in all cases except for azimuth at station #1 and elevation at the greater degree of smoothing. Increased variability of the bow wind profiles occurs because of interaction between wind and (moderate) ocean waves. This effect would be most evident in the elevation data and it is interesting to note that bow and mast elevation records become similar as smoothing time increases. (If the apparent wind fluctuations were due to the motion of

the anemometers on the rolling ship, the mast fluctuations would be uniformly larger, because the mast anemometer is further from the axis of the ship's rotation.)

The standard deviations tend to decrease as fetch increases. This is expected because as fetch increases, the effects of land-induced mechanical turbulence on the wind profiles diminish. Note that the most distant station (#4) yields the lowest values of σ_A. An anomaly occurs in the elevation data: the mast elevation data from station #4 has the lowest standard deviation, but the bow elevation data has the largest σ_E recorded during the day. It appears that the winds at bow height (approximately 3 meters above the water surface) are more directly influenced by the increased water wave heights noted in the vicinity of station #4. However, this phenomenon did not appear on all observing days.

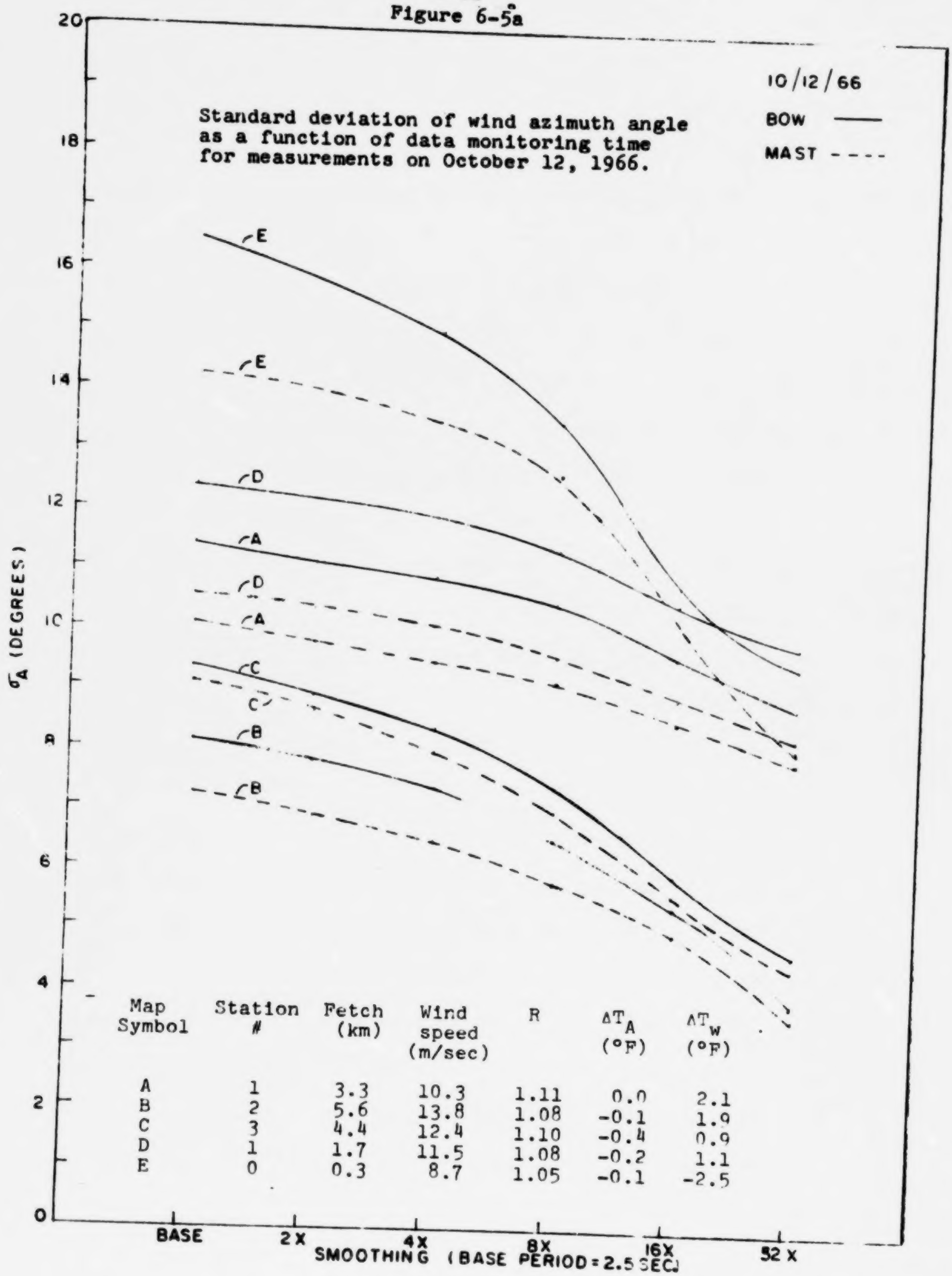
The σ_A values decrease more slowly than the σ_E values with increased smoothing. This occurs because the horizontal (azimuth) wind fluctuations have longer characteristic periods than the vertical (elevation). Examination of Figures 6-4a and 6-4b shows that only about one tenth of the total variance (the square of the standard deviation) in the vertical wind component is caused by motions with periods of one minute or greater, while over one half of the total variance in the horizontal component is caused by "long period" (greater than one minute) fluctuations.

October 12, 1966

This day began with a high (8,000 foot) overcast at sunrise. Moderate to strong winds from the west and northwest occurred throughout the day and the overcast cleared completely by the early afternoon hours. Temperatures were lower than those of the previous day: 49°F was reported at sunrise at Logan airport and the maximum for the day, 55°F, was reported at 1:00 PM EDT. Maximum wind speed for the day was approximately 25 mph, observed during the early afternoon hours. Figures 6-5a and 6-5b illustrate the azimuth and elevation angle wind data collected during this day. Additional information concerning each of the stations is tabulated on the lower part of Figure 6-5a. The following observations may be noted from the figures:

> Both σ_A and σ_E are larger by a factor of approximately two compared to the previous day. The increase in turbulent intensities probably results from two causes: increased wind speeds cause greater mechanically induced turbulence and lower air temperatures result in decreased atmospheric stability.
>
> The azimuth data illustrate the effect of overwater air travel more clearly than the elevation data. The σ_A profiles for the "open water" stations #2 and #3 are clearly lower than those for the near-shore stations #0 and #1.

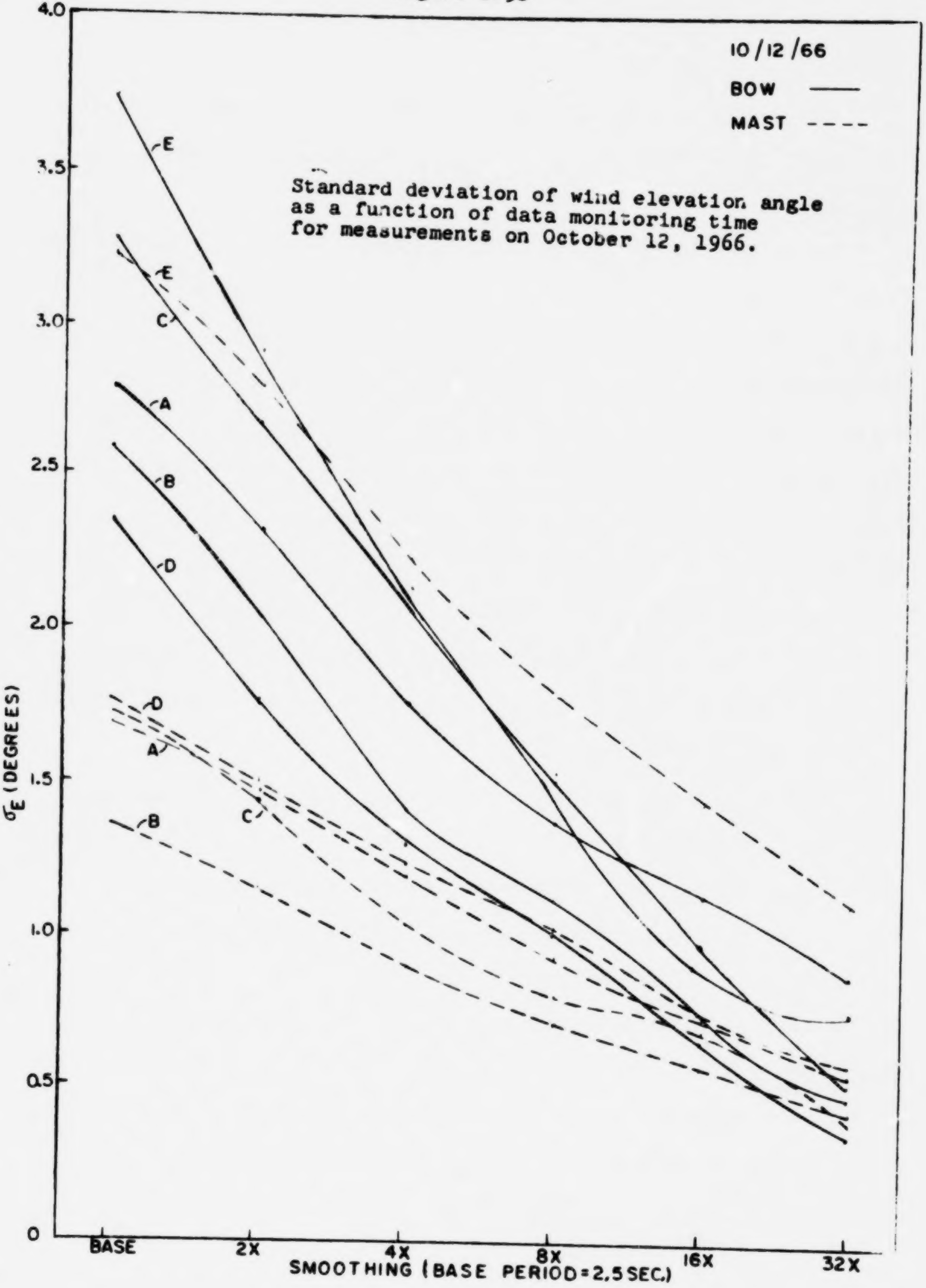
Figure 6-5a



Standard deviation of wind azimuth angle as a function of data monitoring time for measurements on October 12, 1966.

Map Symbol	Station #	Fetch (km)	Wind speed (m/sec)	R	ΔT_A (°F)	ΔT_W (°F)
A	1	3.3	10.3	1.11	0.0	2.1
B	2	5.6	13.8	1.08	-0.1	1.9
C	3	4.4	12.4	1.10	-0.4	0.9
D	1	1.7	11.5	1.08	-0.2	1.1
E	0	0.3	8.7	1.05	-0.1	-2.5

Figure 6-5b



Standard deviation of wind elevation angle as a function of data monitoring time for measurements on October 12, 1966.

Again, the bow σ_A values are everywhere larger than for the mast. The ratio ($\sigma_{A,bow}/\sigma_{A,mast}$) is nearly constant for all degrees of smoothing.

Azimuth data illustrate the expected difference between "overland" and "overwater" turbulent diffusion rates, i.e., the σ_A values for station 0 (0.3 km fetch) are more than twice the values measured at station 2 (5.6 km ketch). This ratio is maintained for the 32X (80 second) smoothing which describes the long period wind perturbations primarily responsible for dispersion within plumes from large, single-point sources.

Averaged values of R (ratio of mast to bow wind speed) are lower than on the previous day. Increased wind speed and turbulent mixing result in diminished vertical variability in observed wind speeds.

Mast σ_E values are nearly the same for all stations except 0, very near the shore line. Station 0 values are large, reflecting mechanical turbulence in the atmosphere near the city. Bow σ_E values follow a mixed pattern; the highest values occur at near-shore station 0, but next highest values occur at station 3, an open-water station. The large values at station 3 reflect the interaction of the wind and the ocean waves very near the ocean surface. Obviously, conclusions concerning the variability of σ_E with overwater travel path depend strongly upon the altitude of measurement for σ_E.

As was observed on October 11, the decrease in σ-values between the base period (2 1/2 seconds) and the 32X-smoothing is much larger for the elevation (vertical wind) than for the azimuth (horizontal wind).

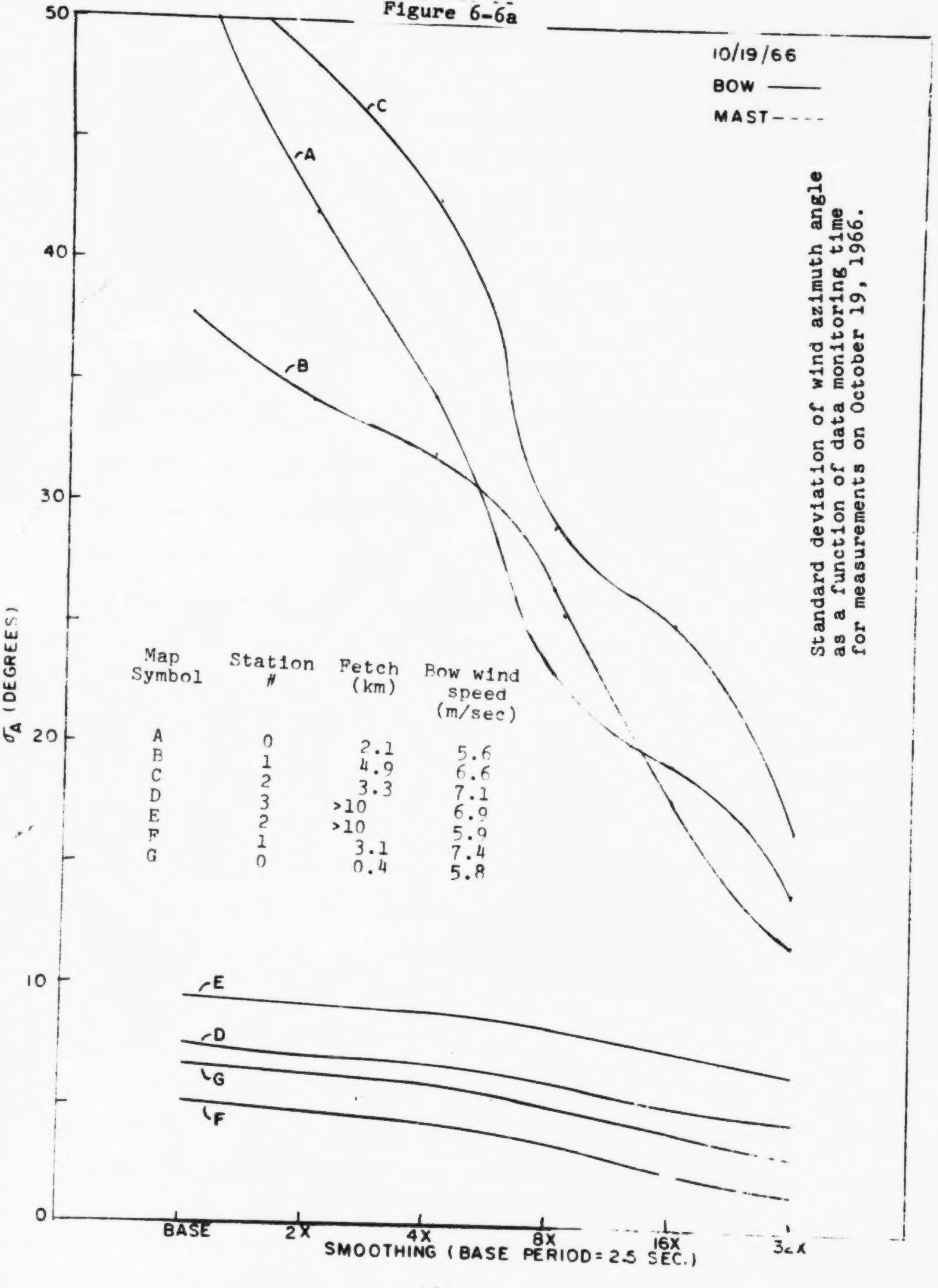
October 19, 1966

The passage of a coastal storm caused heavy precipitation and easterly winds during this day. The data for this day illustrate the variability which can be associated with storm conditions. Approximately one half inch of rain was recorded at Logan Airport during the first three observing hours but only 0.15 inch during the remaining three hours. Air temperature varied between 49°F and 53°F. Wind direction was easterly during the early observing hours, but (coinciding with the decrease in precipitation intensity) then shifted to northeast.

Only the bow system was operated during this day and the σ_A and σ_E data from these observations are summarized in Figures 6a and b. The rainfall caused an imbalance in the bivane anemometer because the vane surfaces were wetted throughout the day. However, wind speed was sufficiently high that the imbalance of the vane was unimportant.

Figures 6-6a and 6-6b and supporting data suggest a mixed pattern for the σ_A and σ_E data and illustrate the difficult analysis problem which is caused by storm conditions. Anomalously high σ_A readings at the first three stations (i.e., 0.1 & 2) result from data obtained during a period of heavy rainfall. During travel between

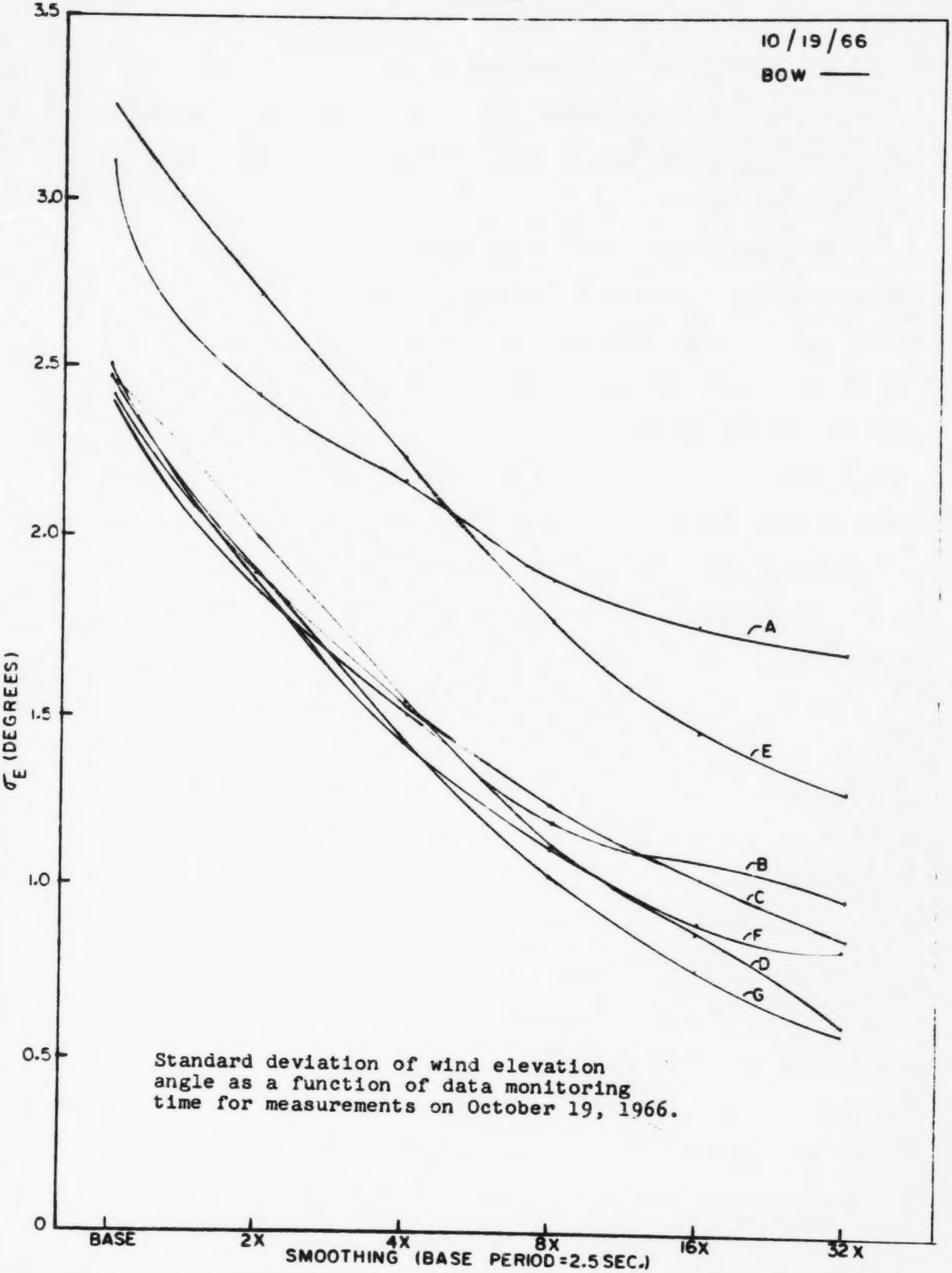
Figure 6-6a



Map Symbol	Station #	Fetch (km)	Bow wind speed (m/sec)
A	0	2.1	5.6
B	1	4.9	6.6
C	2	3.3	7.1
D	3	>10	6.9
E	2	>10	5.9
F	1	3.1	7.4
G	0	0.4	5.8

Standard deviation of wind azimuth angle as a function of data monitoring time for measurements on October 19, 1966.

Figure 6-6b



Standard deviation of wind elevation angle as a function of data monitoring time for measurements on October 19, 1966.

stations 2 and 3, rainfall intensity changed to "light" and the wind shifted to the northeast. All remaining stations completed during the day (symbols D,E,F, and G) exhibited much lower results for σ_A.

A similar pattern is not exhibited by the σ_E data. A feature of the elevation records, consistent with data for other study days, is that most of the variance in the vertical wind component is associated with motions having time scales less than one minute in length.

Although it would be expected that the elevation data record would be more sensitive than the azimuth record to the existence of rainfall, the opposite occurs this day. In fact, the elevation record for this day exhibits less variability than on any other experimental day.

The σ_A data illustrated in Figure 6-6a demonstrate that lateral mixing rates in the atmosphere can change by one or more orders of magnitude within a short time. This change in turbulence intensity was associated with a discrete storm situation although such changes would usually be expected to occur only during a longer time period.

October 28, 1966

This was the fourth successive day of a persistent high pressure occurrence in the Boston area. A well developed subsidence inversion had caused the formation of a dense layer in the lowest 3,000 ft. of the atmosphere over urban and suburban areas. The haze layer was particularly noticeable from offshore viewing points, where the local air was much clearer.

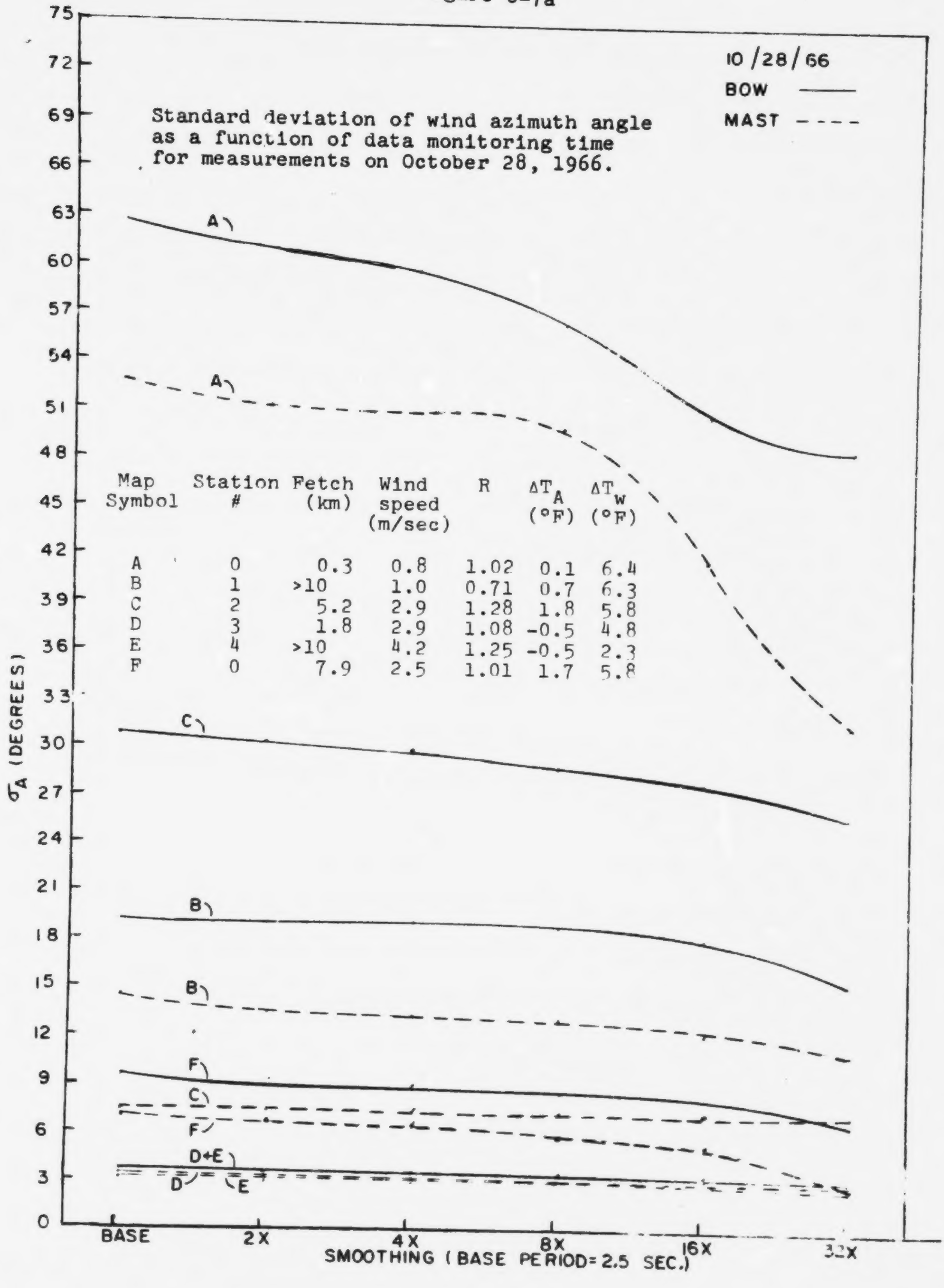
Surface weather was typical of an autumn, high pressure situation. Daytime temperatures were relatively warm, reaching a mid-afternoon maximum of 65°F. Light winds from the southwest were interrupted by a sea breeze circulation which became established at approximately 1100 EDT. (A similar synoptic weather pattern in the mid-summer would lead to the development of a local sea breeze at approximately 0900 EDT). Maximum daytime wind speed was approximately 7 mph which occurred during the peak of the sea breeze circulation at 1400 EDT.

Anemometer data collected during this day are of particular interest because of the development of a steady sea breeze circulation during the observing period. Figures 6-7a and 6-7b contain σ_A and σ_E data similar to those for the days previously discussed. Bow data (both elevation and azimuth) are larger than simultaneous mast data.

Symbol A data, collected at Station "O", were obtained before the sea breeze circulation developed. The wind direction during this period was WNW (285°). All other data are sea breeze cases with winds between 75° and 135°.

Both σ_A and σ_E readings for case A are significantly larger than other readings obtained during the day. The increased turbulence during this observing period is caused primarily by the mechanical influence of flow over the city: the waterfront area was approximately 300 meters upwind from the station during this observation period. Late afternoon observations at the same station (symbol F on the figures) indicated much lower turbulence levels associated with an on-shore sea breeze flow over the smooth ocean surface.

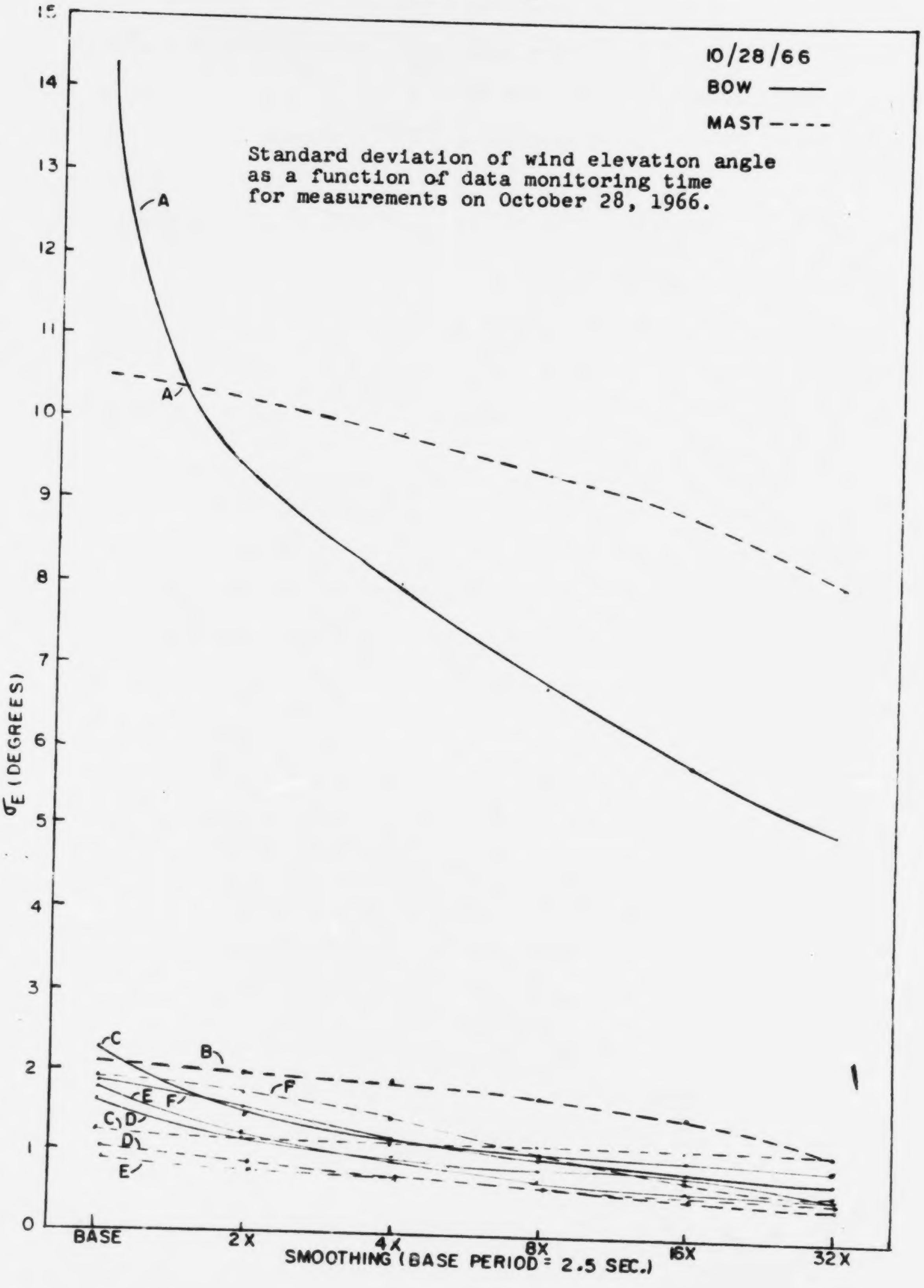
Figure 6-7a



Standard deviation of wind azimuth angle as a function of data monitoring time for measurements on October 28, 1966.

Map Symbol	Station #	Fetch (km)	Wind speed (m/sec)	R	ΔT_A (°F)	ΔT_w (°F)
A	0	0.3	0.8	1.02	0.1	6.4
B	1	>10	1.0	0.71	0.7	6.3
C	2	5.2	2.9	1.28	1.8	5.8
D	3	1.8	2.9	1.08	-0.5	4.8
E	4	>10	4.2	1.25	-0.5	2.3
F	0	7.9	2.5	1.01	1.7	5.8

Figure 6-7b



Standard deviation of wind elevation angle as a function of data monitoring time for measurements on October 28, 1966.

Observations of σ_E during sea breeze conditions are unusually uniform, regardless of the overwater travel distance of the local winds. For a 10 second smoothing period (4x symbol), variability within the sea breeze data is approximately equal to a factor of two, whereas the off-shore winds are about four times the largest of the sea breeze observations.

During sea breeze conditions σ_A data display greater variability than σ_E, but even the largest sea breeze values (bow data for station 2) are a factor of two lower than the values for the off-shore wind case.

If, as a first approximation, σ_A and σ_E are considered to be proportional to the horizontal and vertical dispersive capacity of the local atmosphere, it will be clear that mixing rates over the ocean (away from the shore) during on-shore wind conditions are lower by a factor between two and ten than mixing rates for off-shore, overland flows.

Mast and bow wind speeds observed near the shore at station 0 were approximately equal on this day. Away from the shore, mast speeds were significantly larger for station 1 where bow speed exceeded mast speed for the only time during the entire study. This anomaly was confirmed by visual observations as the notebook records for this day indicate that calm conditions were verified at mast height when measurable winds occurred at bow level. It appears that a weak circulation existed near the water surface which did not propagate up to mast height.

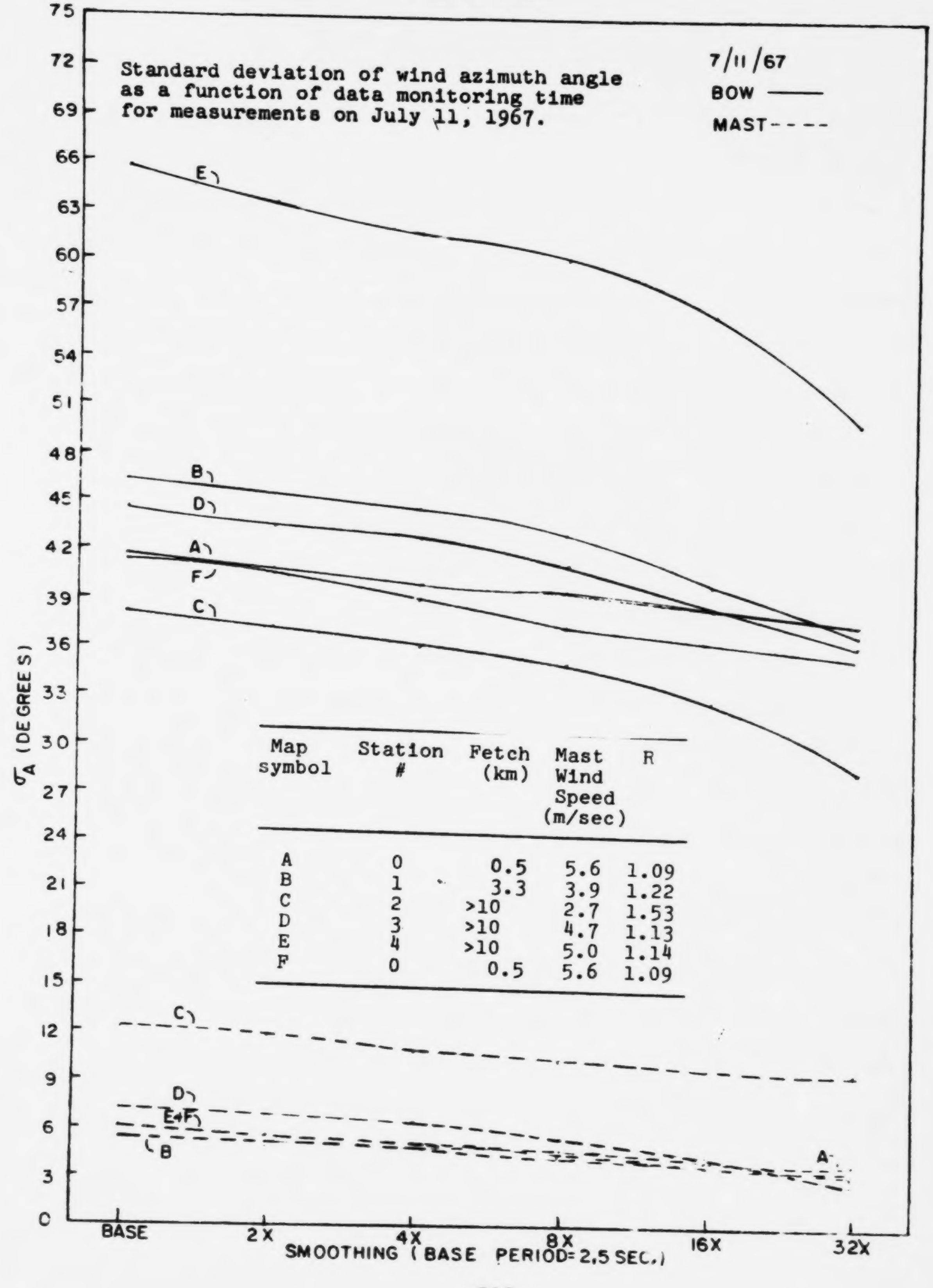
July 11, 1967

Passage of a weak low pressure center off the coast caused this to be a cool, overcast day with easterly winds. On-shore winds were a feature of the synoptic pattern rather than a local, thermally-driven (sea breeze) circulation. A haze layer was well defined over the city area during the morning hours but it became less noticeable as the height of the cloud base decreased during the early afternoon hours. By 1300 EDT the cloud base observation at the U.S. Weather Bureau Station at Logan Airport was 6,000 feet. A trace of rain fell at the end of the observing period (1600 EDT) and light rain continued into the following day.

The σ_A and σ_E summaries for this day are presented in Figures 6-8a and 6-8b. Azimuth data divide clearly between bow and mast observations as all bow σ_A values are greater than mast values by factors of three to ten. For the elevation data, bow values are also larger but the difference is approximately a factor of two. The sea state was high this day, because of storm conditions and visual observations confirm that wind fluctuations at bow level were consistently greater than fluctuations at mast height. Thus, during rough sea conditions, atmospheric turbulence intensity changes significantly within the first 11 meters above the ocean surface.

Because of the storm conditions, the mechanical turbulence effect, estimated by the overwater travel path for the winds, is minimal. The two stations with small fetch (symbols A and F) yield some of the lowest σ_A and σ_E data indicating that during a stormy day the sheltering effect of nearby land is more important than increased roughness of the land surfaces.

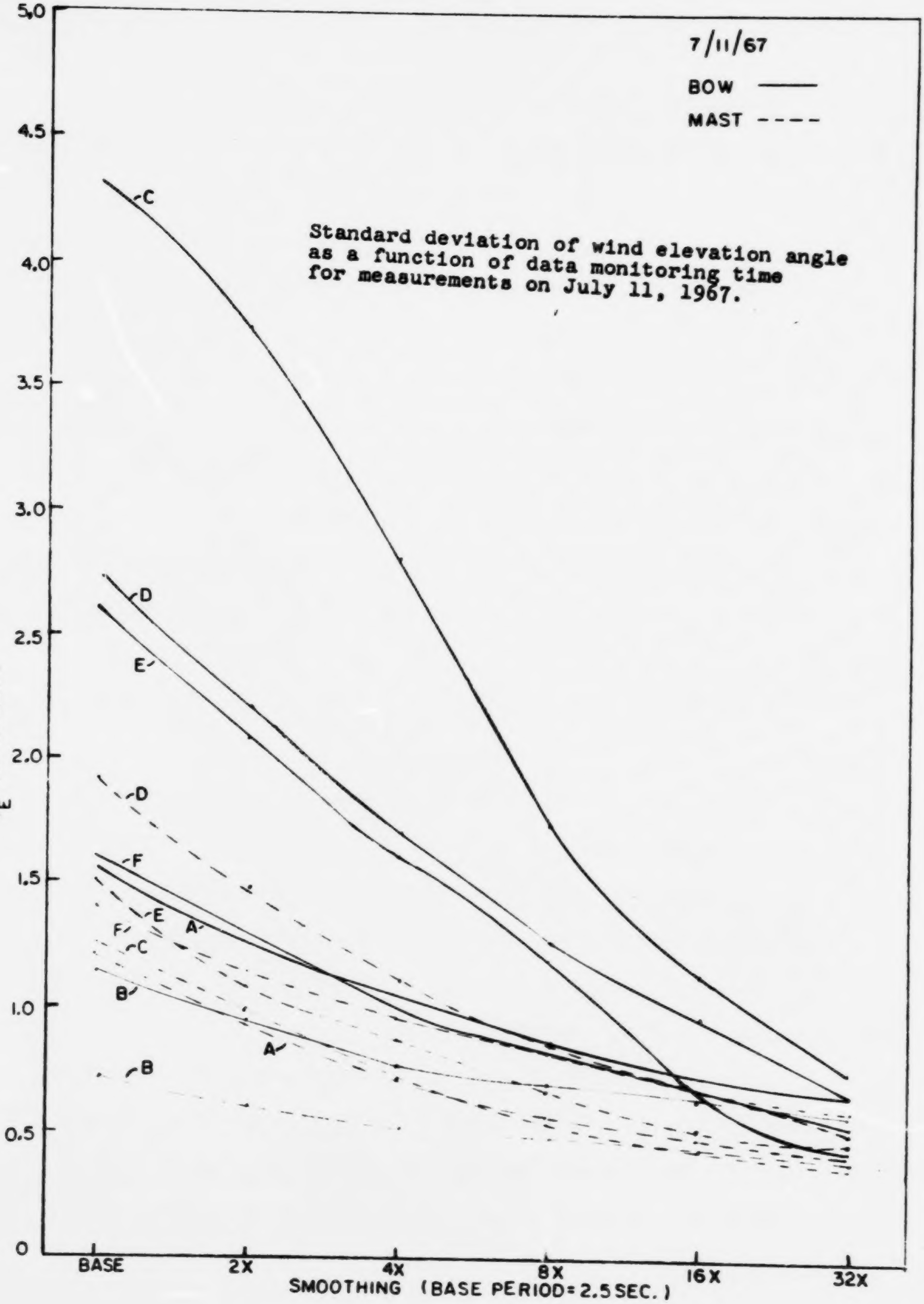
Figure 6-8a



Standard deviation of wind azimuth angle as a function of data monitoring time for measurements on July 11, 1967.

Map symbol	Station #	Fetch (km)	Mast Wind Speed (m/sec)	R
A	0	0.5	5.6	1.09
B	1	3.3	3.9	1.22
C	2	>10	2.7	1.53
D	3	>10	4.7	1.13
E	4	>10	5.0	1.14
F	0	0.5	5.6	1.09

Figure 6-8b



Standard deviation of wind elevation angle as a function of data monitoring time for measurements on July 11, 1967.

F. Summarized data from the Boston Harbor Experiments

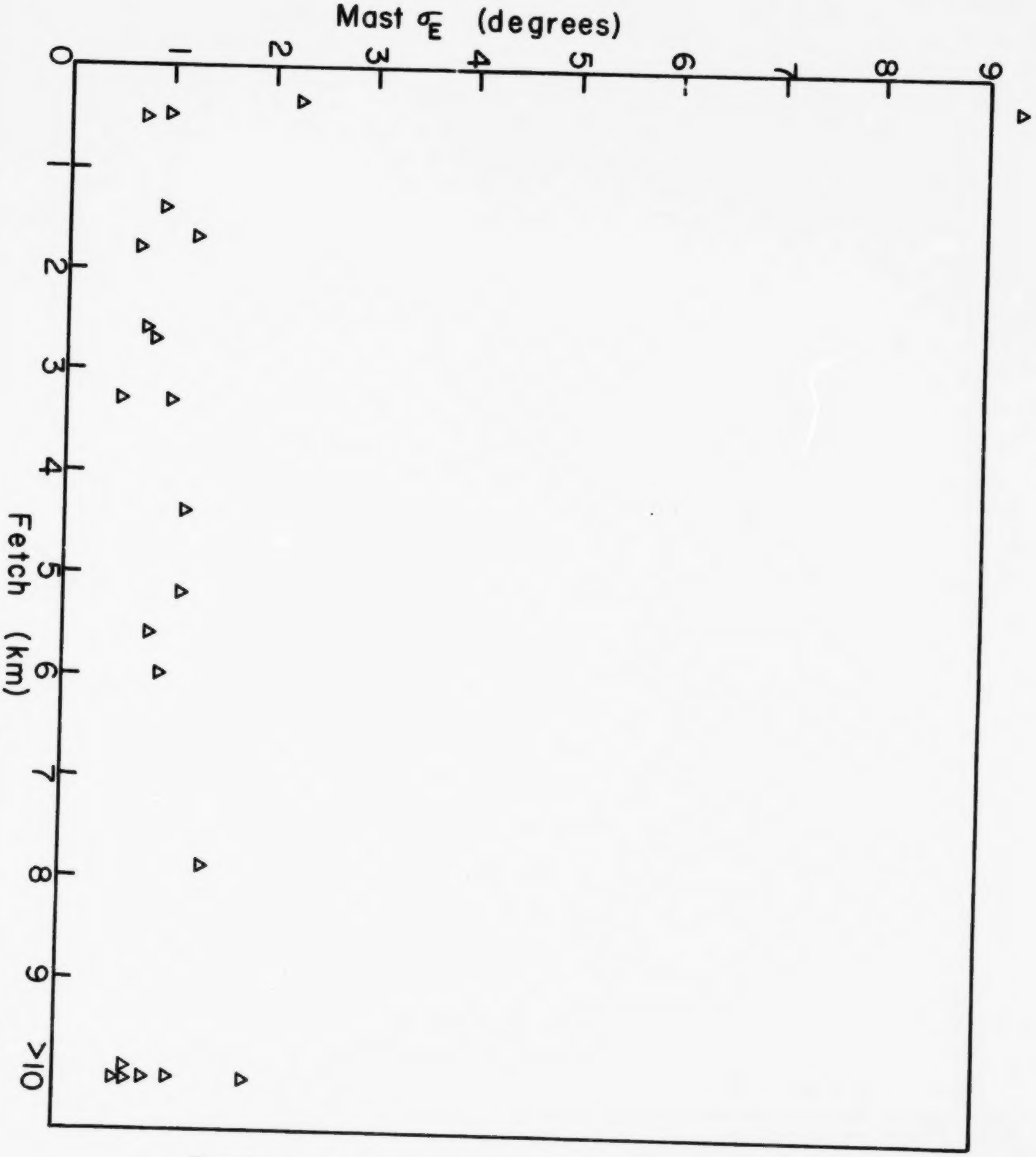
The daily data summarized above indicate great variability in the observed atmospheric turbulence data, i.e., σ_A and σ_E can differ by a factor of five or more on days having differing weather conditions. To examine the average effect of overwater travel distance and mean wind speed upon turbulence parameters, all data obtained during the Boston Harbor experiments were analyzed. Results of the data analysis are presented in a series of figures in this section. In all figures, circles are used to illustrate azimuth angle standard deviations, triangles for elevation angle standard deviations, and squares for along-the-wind fluctuations, measured by the ratio $\sigma_S/\overline{S}$ where σ_S is the standard deviation of the wind speed data set for a station, and $\overline{S}$ is the average value for the set. Symbols are open for mast data and solid for bow data.

The influence of overwater travel distance of the wind upon angular standard deviation is examined in Figures 6-9a-d and 10. Figures 6-9a through 6-9d illustrate σ_A and σ_E data for all five days. The following observations are based upon these figures:

(1) Wind fluctuations (both σ_A and σ_E) are generally larger at bow height than at mast height.

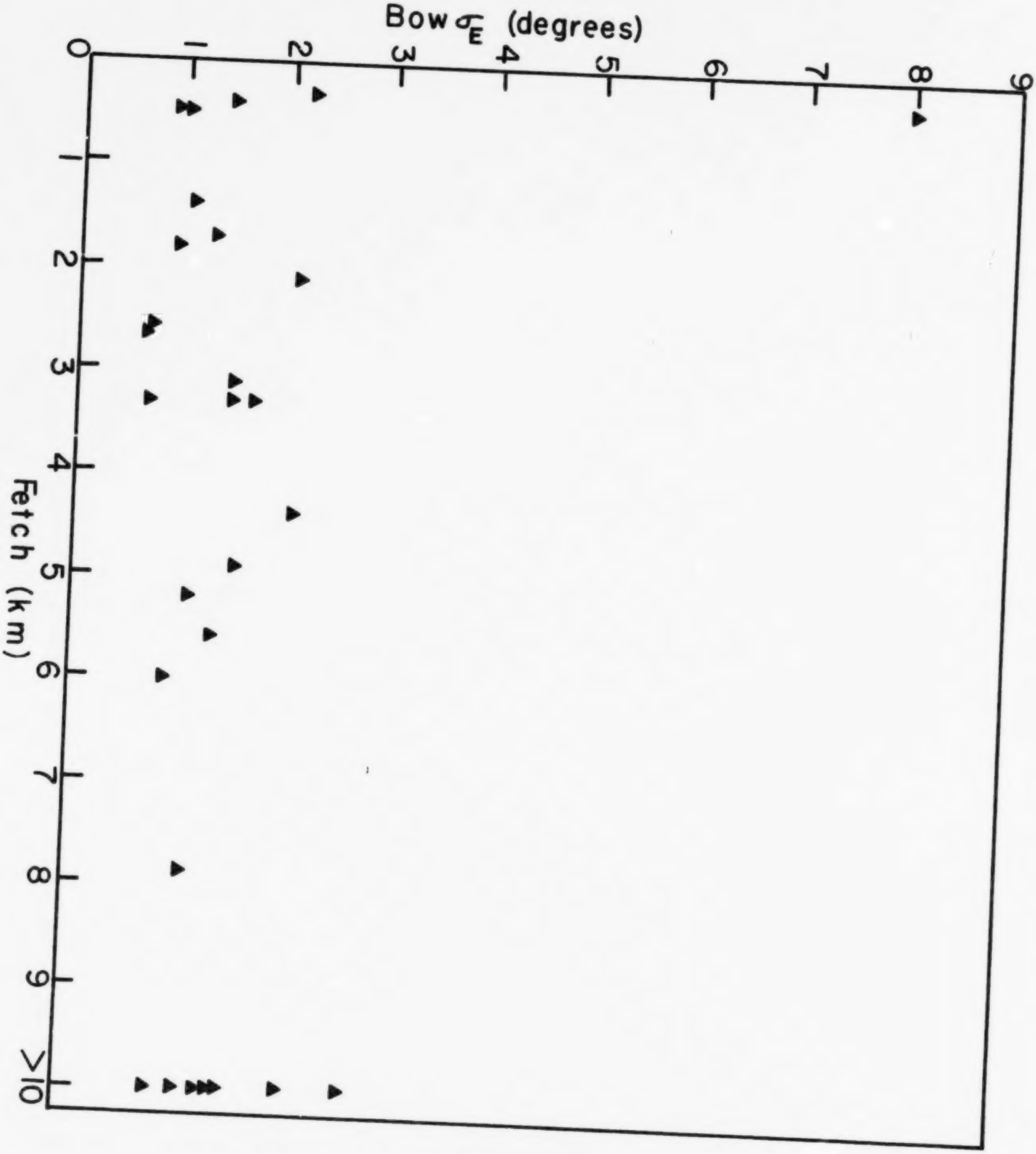
(2) No evident relationship exists between fetch and σ_A or σ_E observations. Analysis of data from individual days has indicated the enhancement of turbulent intensities within the first kilometer downwind from the built-up water front area,

Figure 6-9a



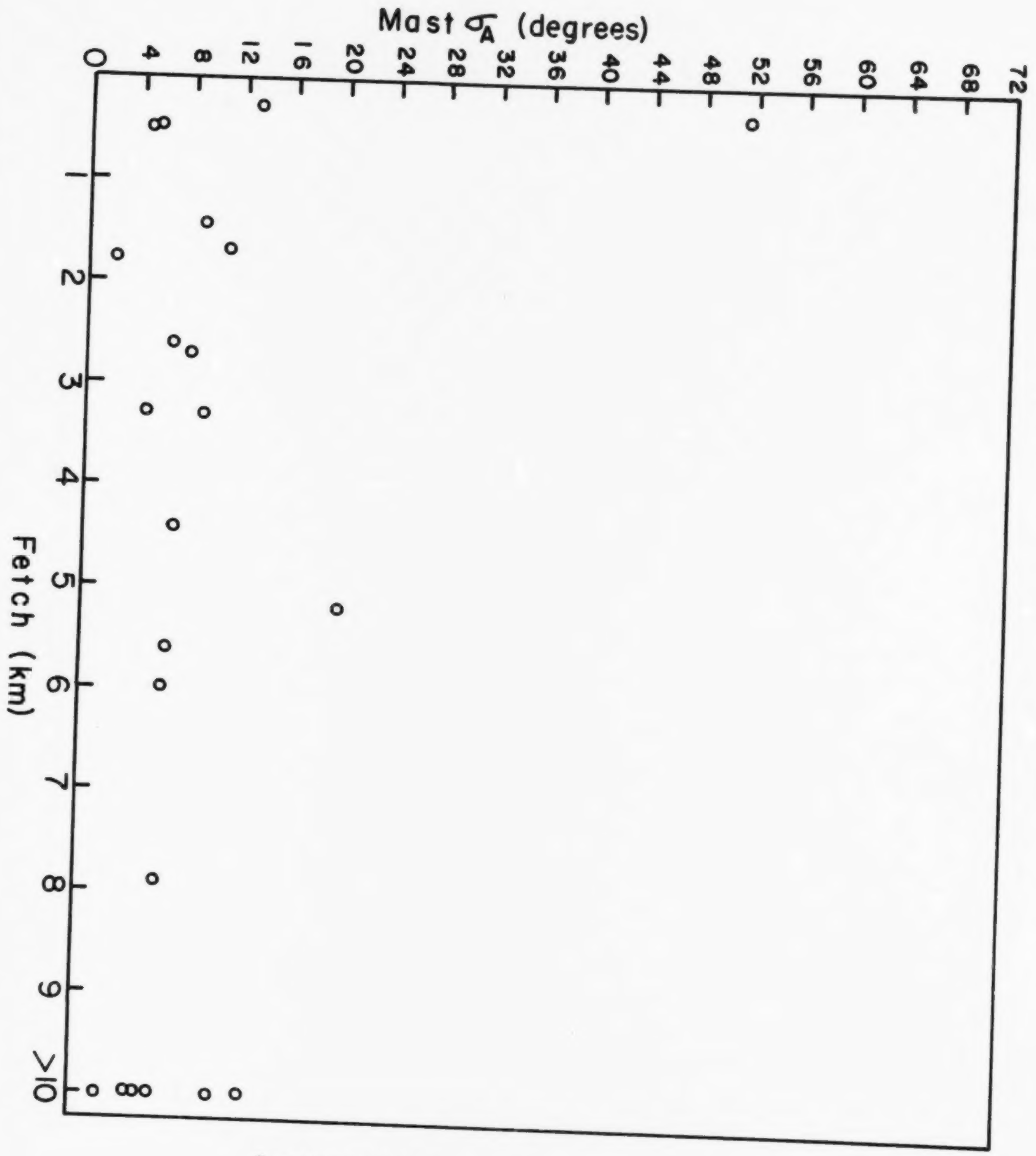
Standard deviation of wind elevation angle observed at the mast location for all five case study days, plotted against wind fetch.

Figure 6-9b



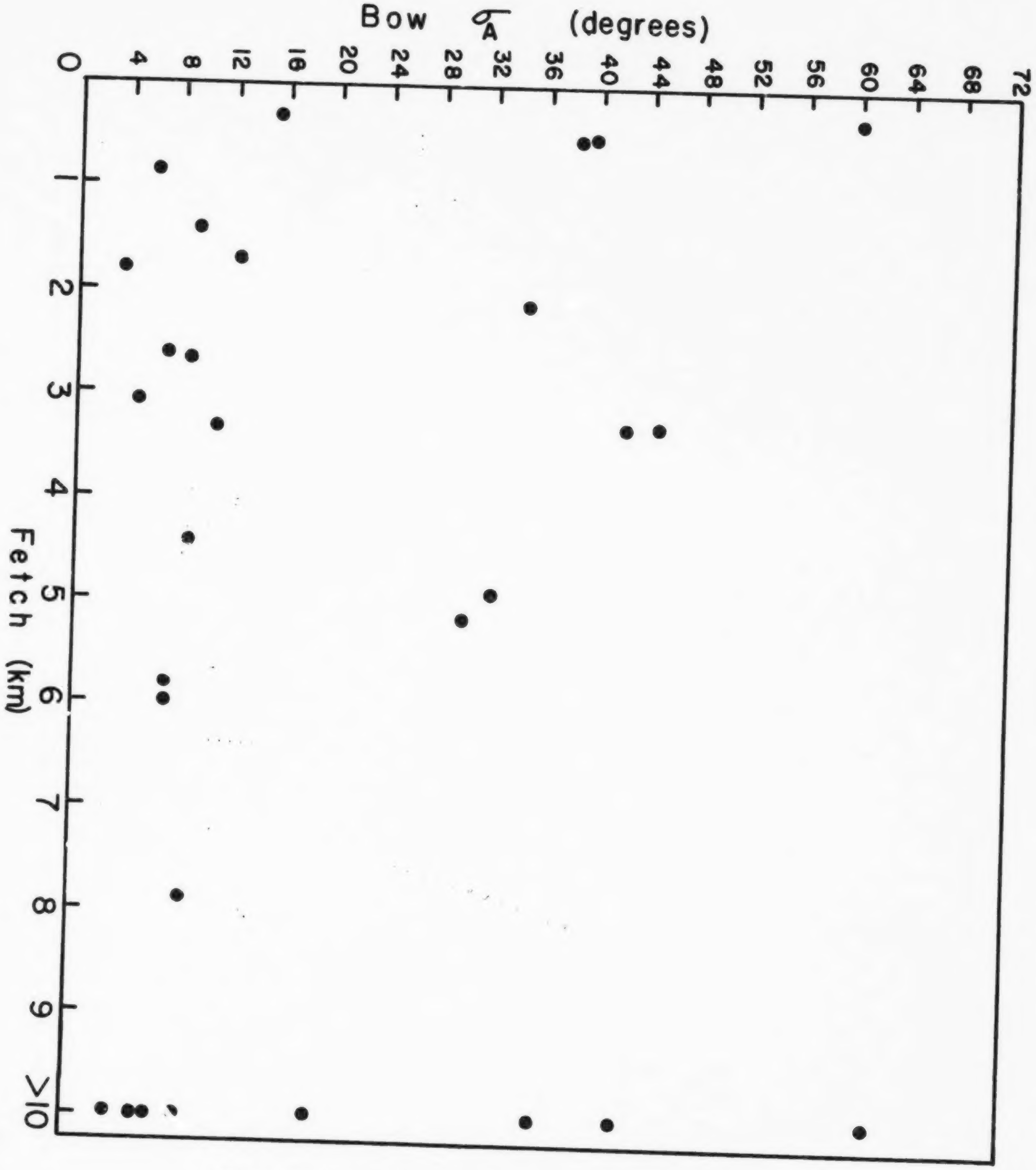
Standard deviation of wind elevation angle observed at the tow location for all five case study days.

Figure 6-9c



Standard deviation of wind azimuth angle observed at the mast location for all five cast study days, plotted against wind fetch.

Figure 6-9d



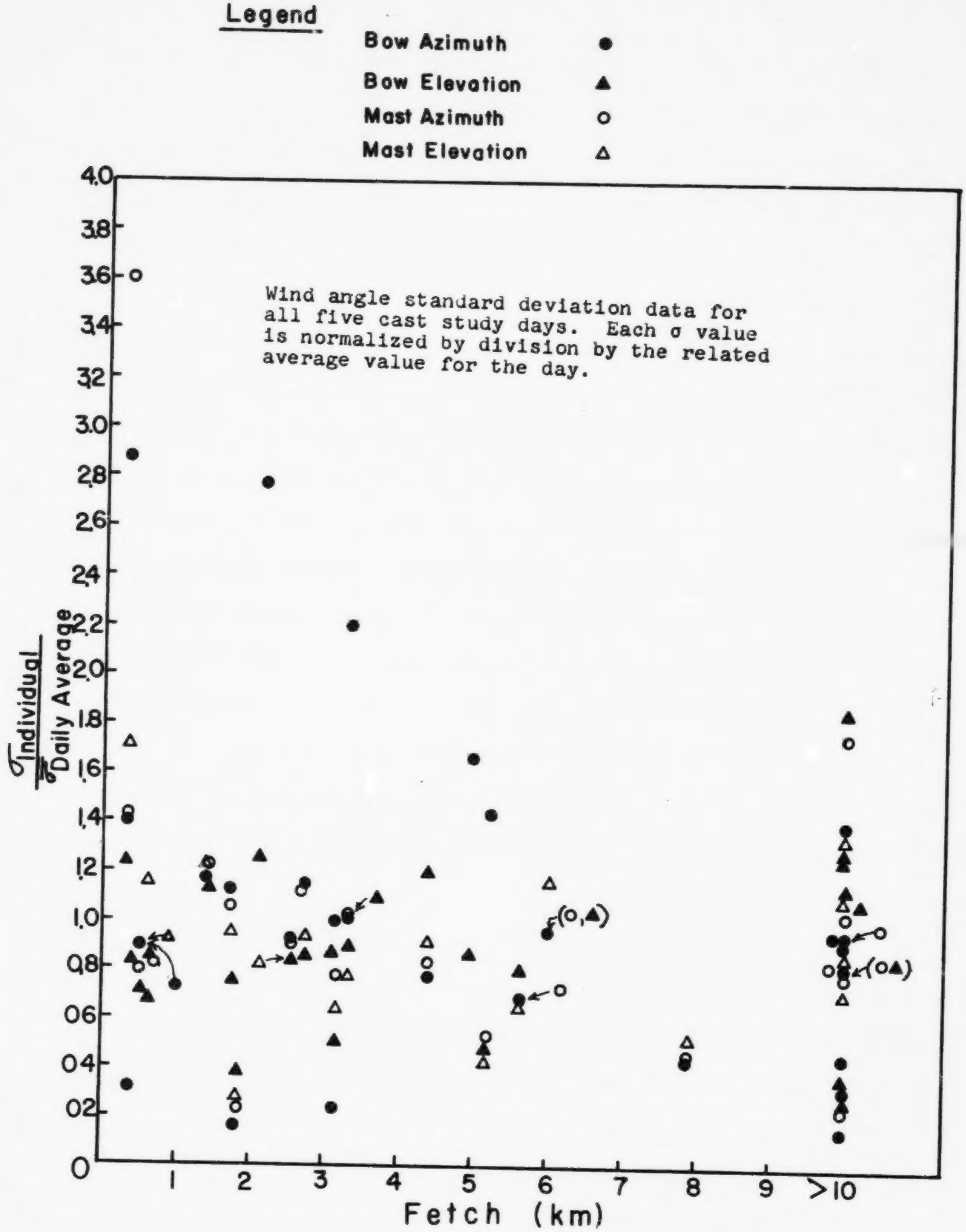
Standard deviation of wind azimuth angle observed at the bow location for all five case study days, plotted against wind fetch.

but this effect is masked by the large day-to-day variability shown in Figures 6-9a and b. (The enhancement effect of mechanical turbulence probably could be illustrated by averages if the data were normalized with regard to wind speed, atmospheric stability and sea state during observations. However, such an analysis would require a much larger set of observed data.

Figure 6-10 illustrates an attempt to normalize for day-to-day variability in the angular indices, σ_A and σ_E. Each observation of angular standard deviation (azimuth or elevation) was divided by the average value of the same parameter obtained from all observations completed during the day and this ratio was plotted. As expected, some of the largest values of this ratio were obtained for small fetch cases. However, even the open water values (plotted along the ">10" abscissa line) have an average of nearly unity and it is not possible to make a statistically valid determination of the effect of underwater wind travel on the basis of these data. Instead, the mechanical turbulence effects must be deduced by direct analysis of the data collected during individual observing days.

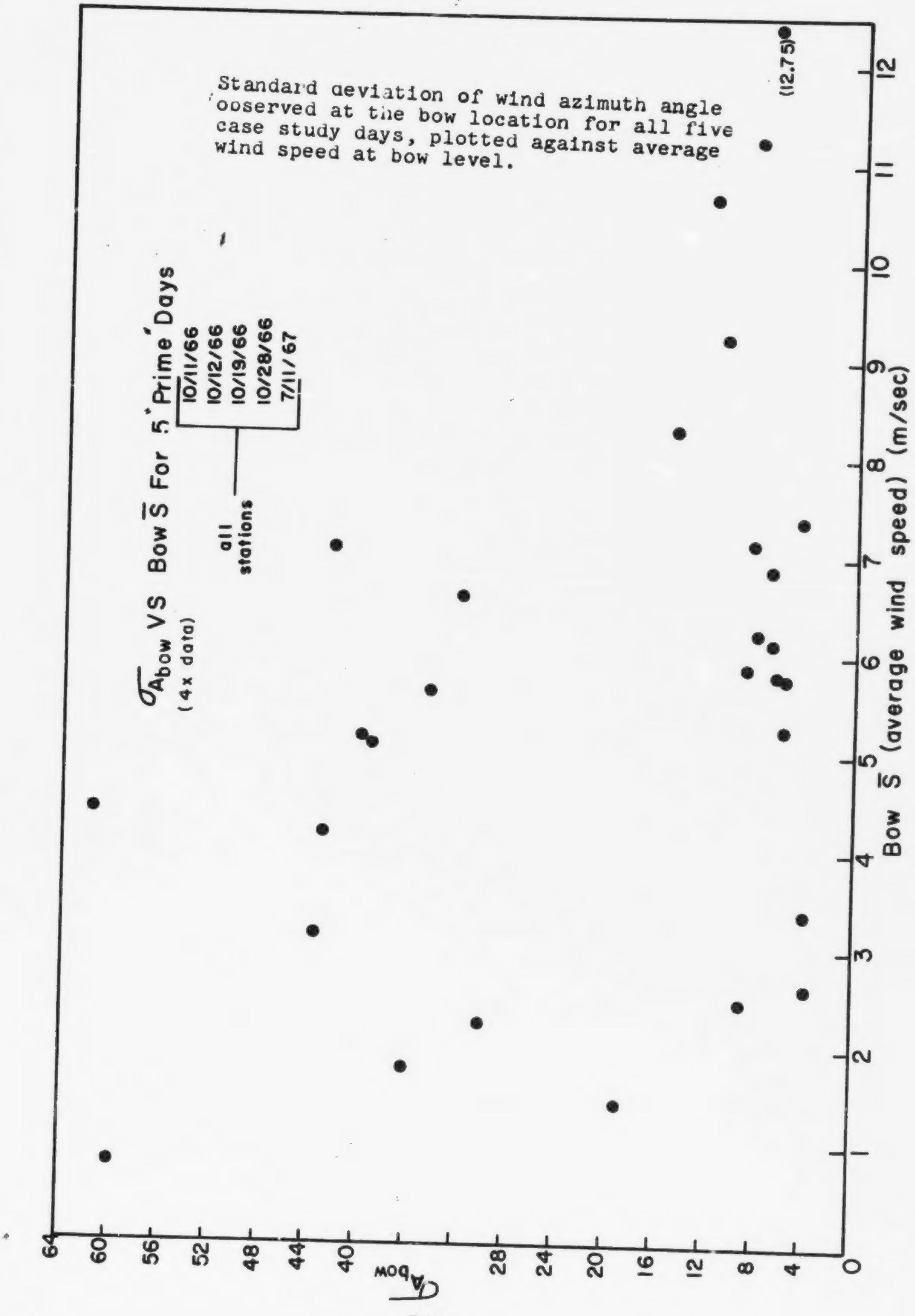
The relationship between the angular fluctuations and average wind speed during the observing period is summarized in Figures 6-11a-d where the bow data are related to the mean wind speed observed by the bow anemometer and the mast data are compared to the **mast** level mean wind speed. The bow level azimuth data exhibit selection by the wind speed, i.e., all the largest values of σ_A were obtained when the mean wind speed was 7 meters/sec

Figure 6-10



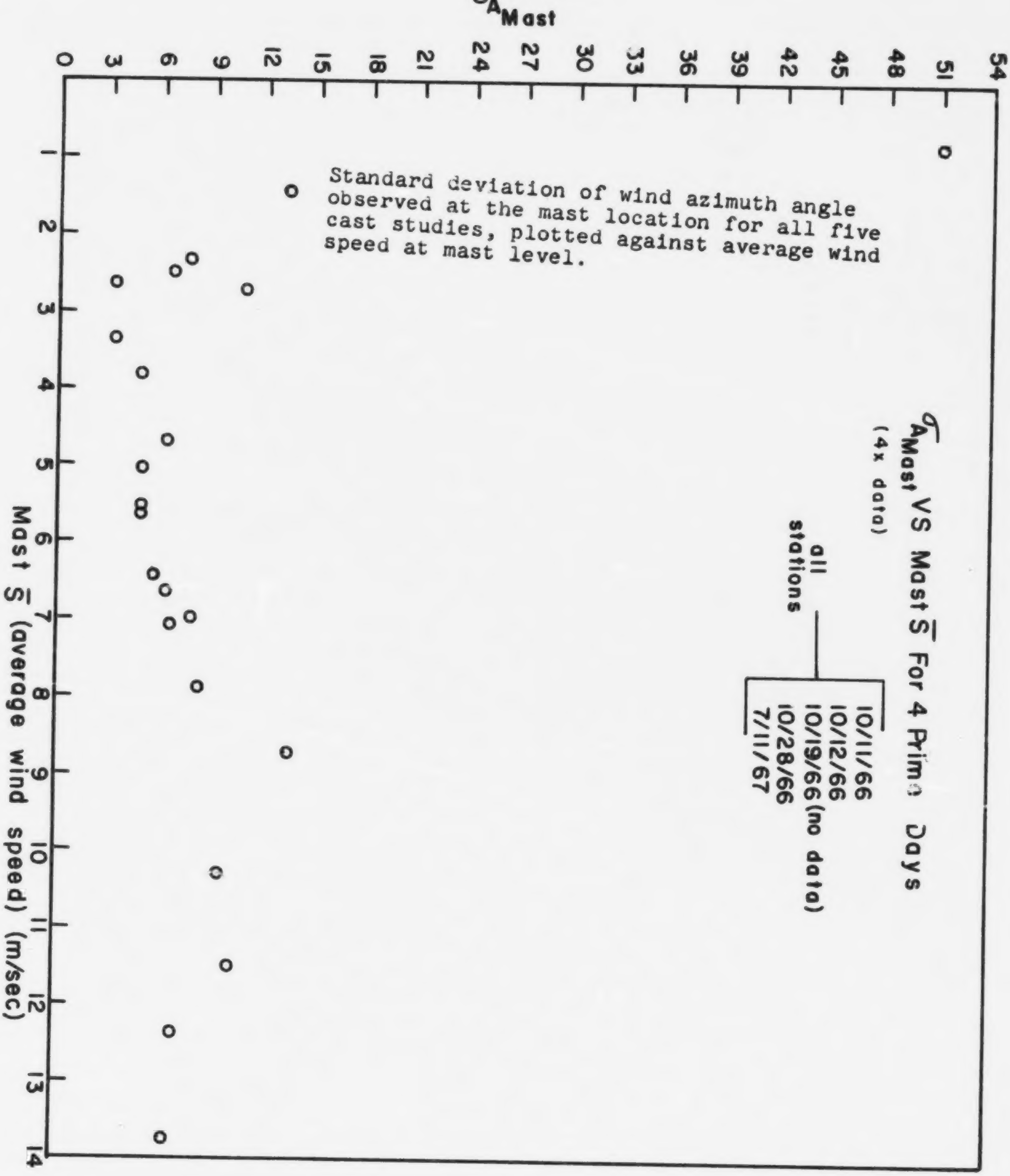
Wind angle standard deviation data for all five cast study days. Each σ value is normalized by division by the related average value for the day.

Figure 6-11a



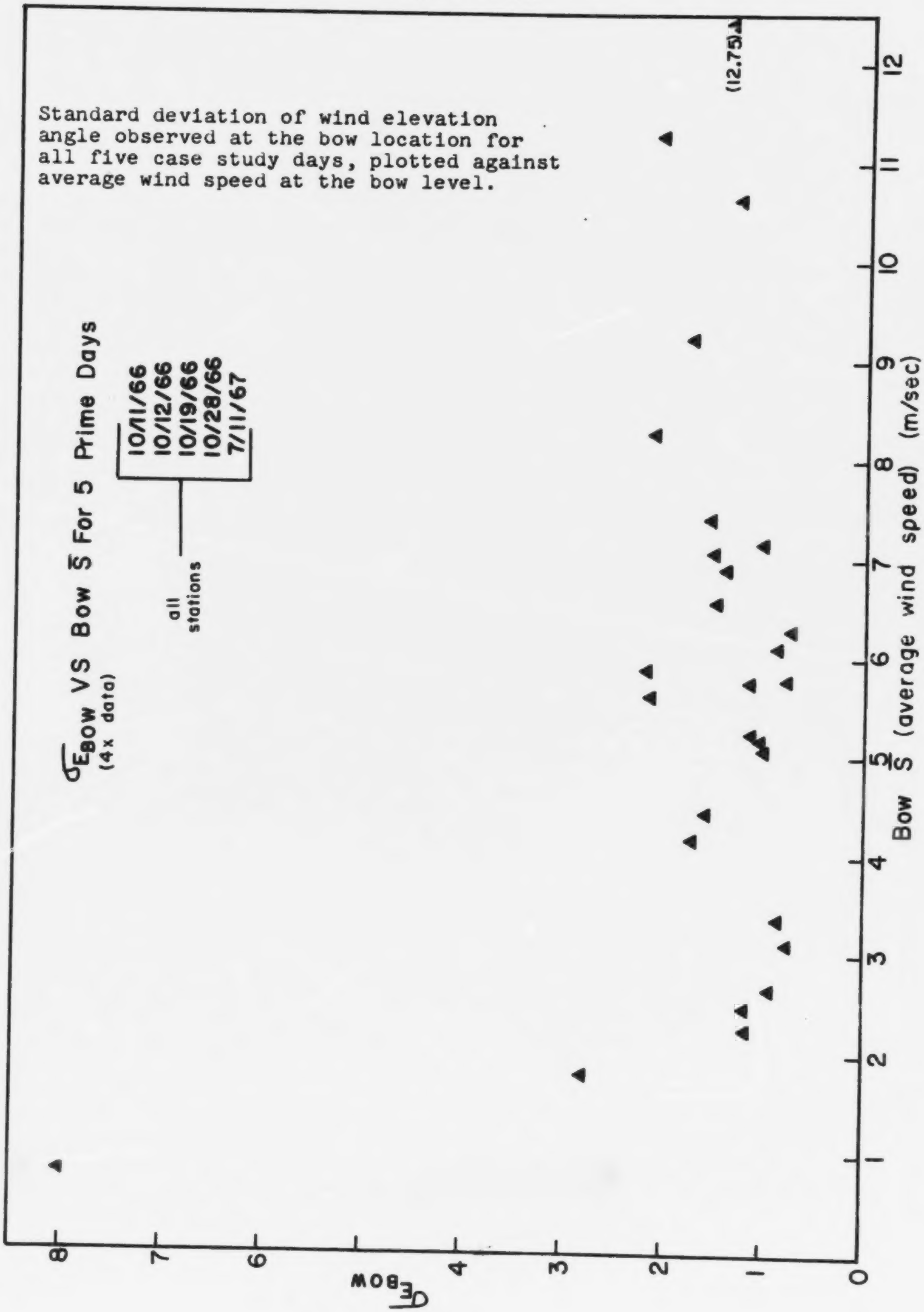
Standard deviation of wind azimuth angle observed at the bow location for all five case study days, plotted against average wind speed at bow level.

Figure 6-11b



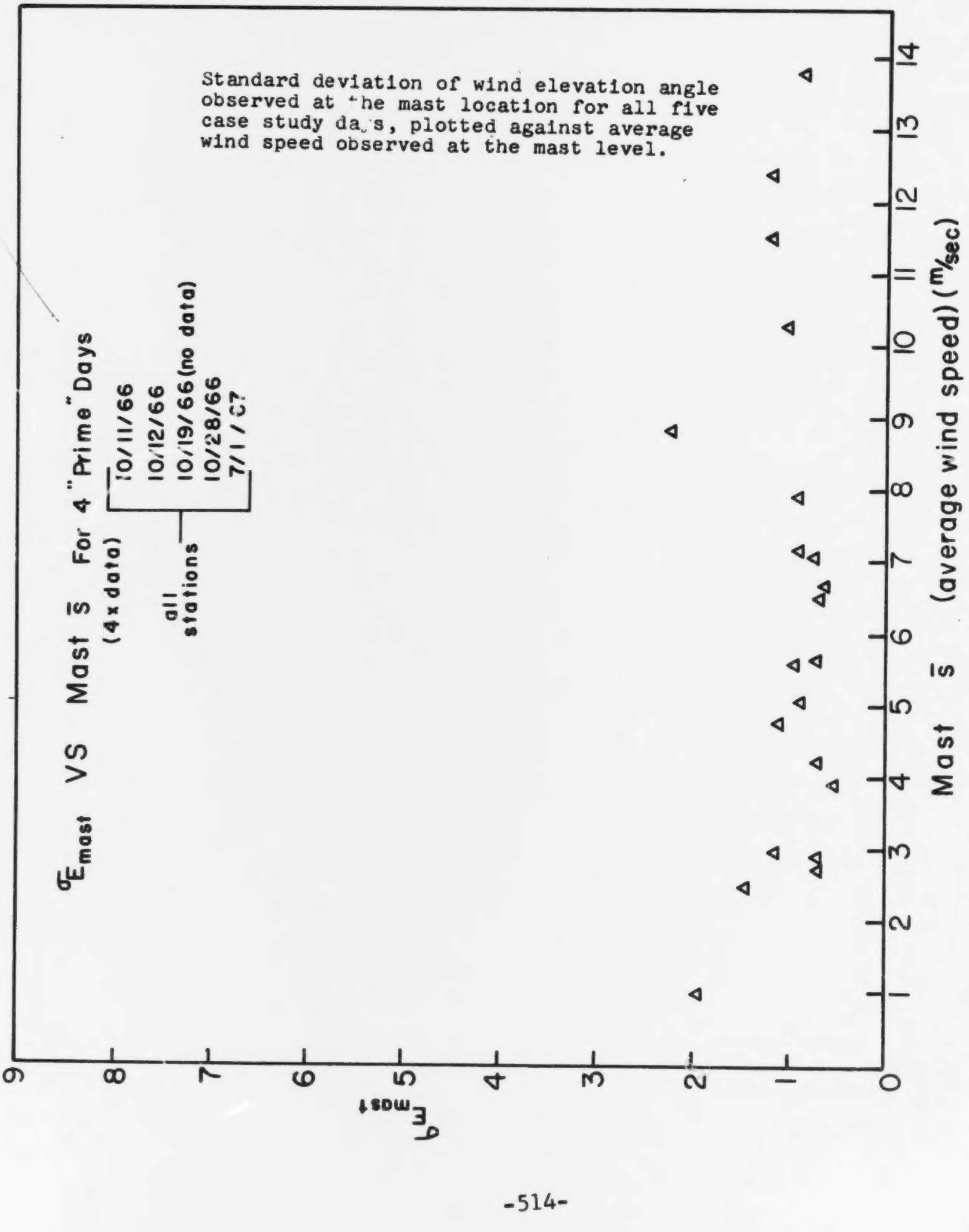
Standard deviation of wind azimuth angle observed at the mast location for all five cast studies, plotted against average wind speed at mast level.

Figure 6-11c



Standard deviation of wind elevation angle observed at the bow location for all five case study days, plotted against average wind speed at the bow level.

Figure 6-11d



Standard deviation of wind elevation angle observed at the mast location for all five case study days, plotted against average wind speed observed at the mast level.

or less although many small values of σ_A were also obtained when the wind speed was light to moderate, at mast level (Figure 6-11b) only one large value of σ_A was recorded at any time. These observations suggest the following interpretation: When the wind speed is light, the interaction of the wind field with local surface waves can cause significant horizontal fluctuations observable at bow level. However, these features of the wind field appear not to propagate to mast height. Therefore, mast σ_A observations, with one exception, are much lower than corresponding bow readings.

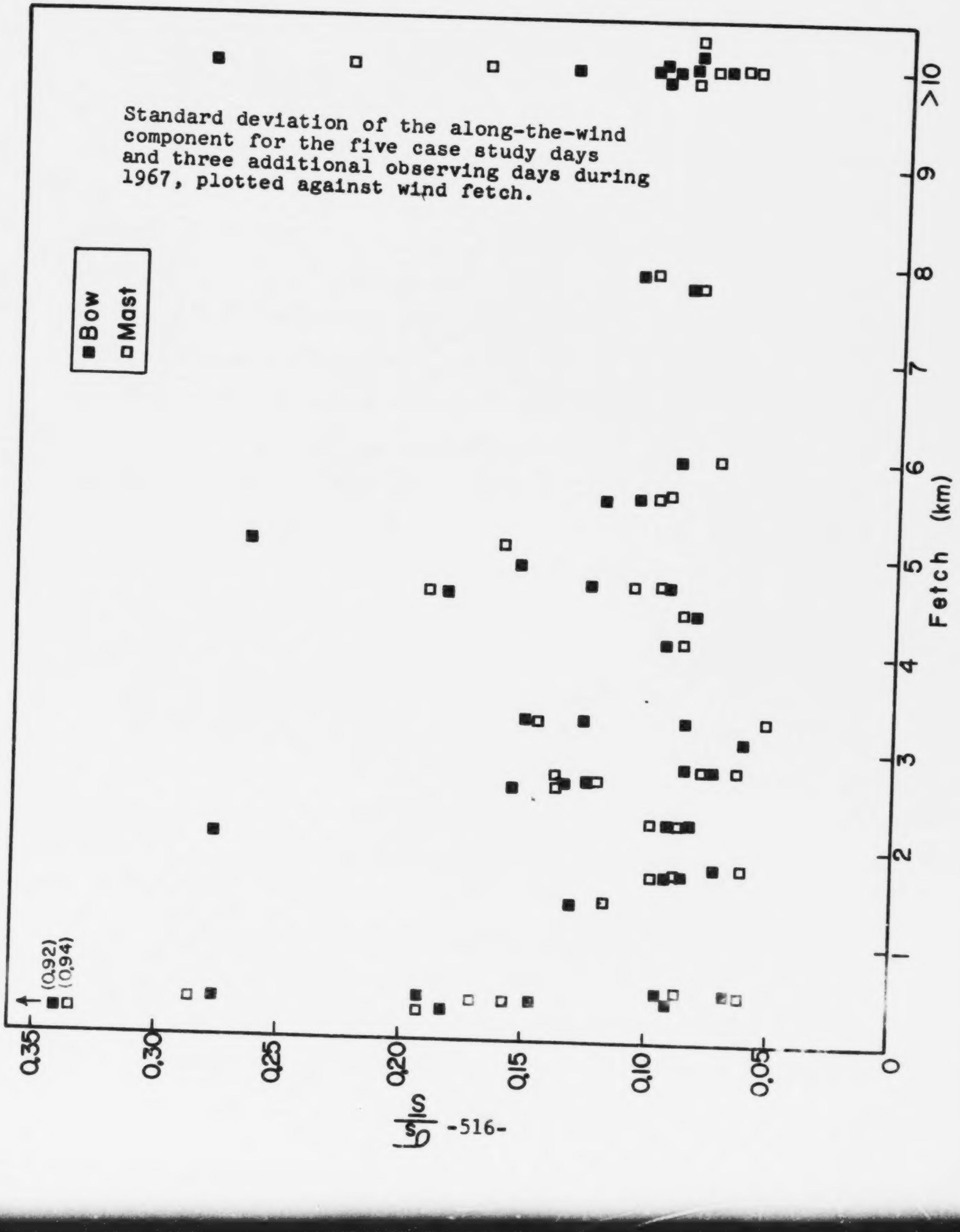
Elevation data at bow and mast level (Figures 6-11c and d) are too few to permit a statistically valid determination of wind speed influence upon vertical wind variability.

Along-the-wind fluctuations, $\sigma_S/\overline{S}$, have been measured for all observing periods and summarized in Figure 6-12. The relationship between $\sigma_S/\overline{S}$ and overwater travel distance, plotted for the five case study days and for three additional days in autumn, 1967, suggests a hypothesis for three categories:

For fetch less than one kilometer (i.e., the wind field immediately downwind from the waterfront) a combination of low and high values of $\sigma_S/\overline{S}$ occurs. The large numbers of high values (above 0.15) indicates mechanical turbulence enhancement downwind from the city. Although some low values occur, their relative number is smaller than the relative number for longer fetch.

For fetch between one and ten kilometers, most values of $\sigma_S/\overline{S}$ are below 0.15. In these cases, mechanical turbulence induced by flow over the city was attenuated but not completely damped out because the observing boat was still operating within the protection of Boston Harbor.

Figure 6-12



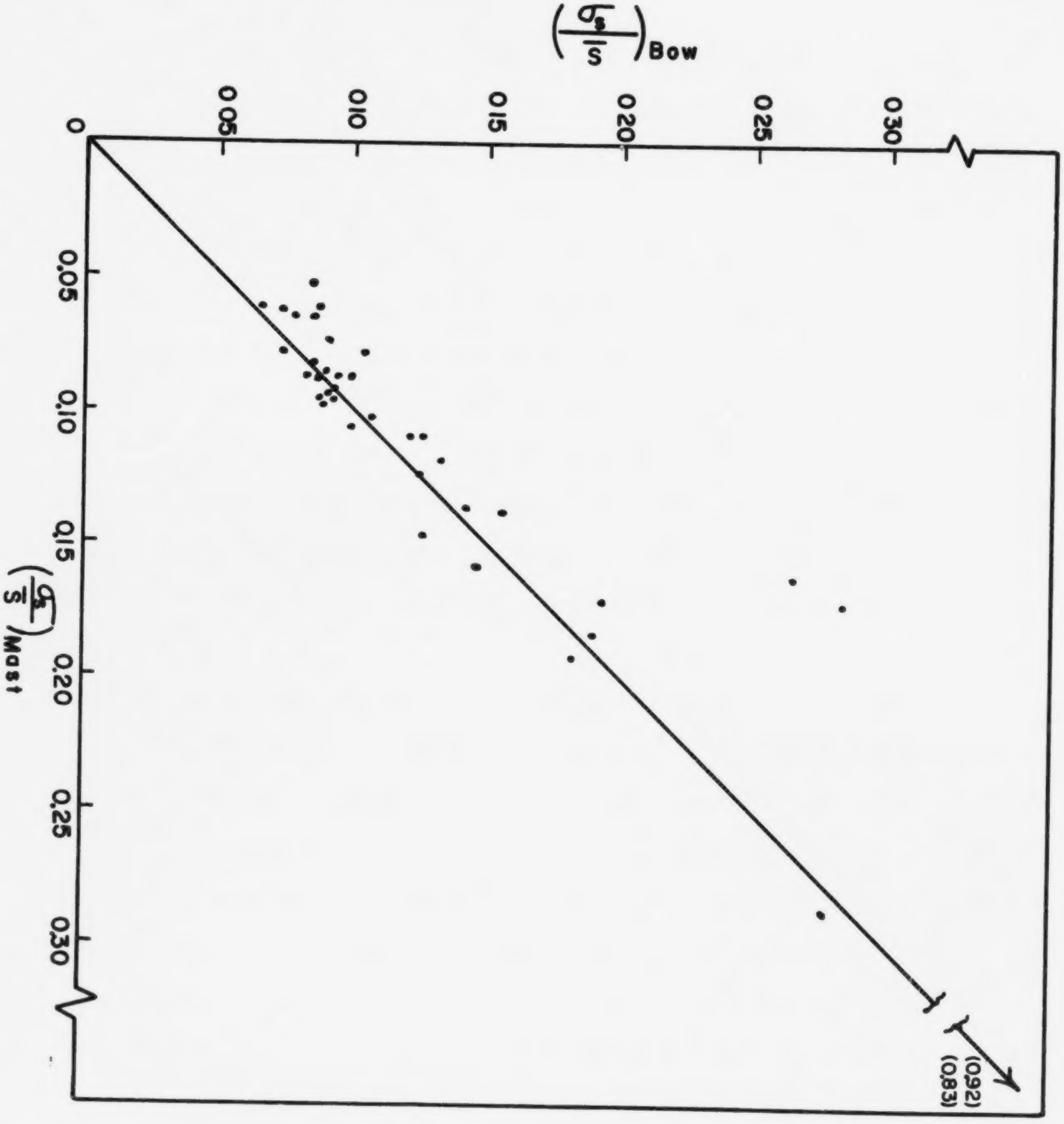
Standard deviation of the along-the-wind component for the five case study days and three additional observing days during 1967, plotted against wind fetch.

For fetch greater than ten kilometers (the open water case) most values of $\sigma_S/\overline{S}$ are small but a few elevated results appear. All larger values occurred during light wind cases,(i.e., average wind speeds less than 2 meters/sec) and these results are not representative. The two largest values occurred when wind varied between calm and a few meters/sec. Thus, the mechanical turbulence effect is especially small when the overwater travel distance for the local wind is 10 kilometers or more.

No attempt has been made to analyse average values of the turbulence parameters because day-to-day variability of synoptic conditions and the combined effects of wind speed, ocean wave height, and mechanical turbulence cannot be separated satisfactorily in the available data set.

An interesting phenomenon noted during the data analysis was that bow and mast ratios of $\sigma_S/\overline{S}$ were very nearly equal for all stations analyzed whereas bow and mast measurements of the angular turbulence indices, σ_A and σ_E did not compare well for most stations. Indeed, as noted in a previous section, markedly different estimates of σ_A and σ_E were obtained at mast and bow levels much of the time. Figure 6-13 contains a plot of all bow and mast pairs of $\sigma_S/\overline{S}$ obtained during the case study days and during autumn, 1967. Only three of the 39 pairs depart significantly from the line denoting equal ratio showing that along-the-wind fluctuations exhibit much greater vertical uniformity than the other parameters studied.

Figure 6-13



Comparison of bow level and mast level along-the-wind standard deviation data for the five case study days and three additional observing days in 1967.

G. Conclusions based upon the Boston Harbor Experiments.

The most striking conclusion derived from the data analysis is the great variability in the observed turbulence parameters and, therefore, the great variability in atmospheric diffusion rates. The diffusion coefficients depend upon fetch, sea state, and synoptic meteorological conditions, particularly wind speed and atmospheric stability, although it is not possible to construct a simple regression relationship between these "predictors" and the observed diffusion coefficients.

It is possible to cite a range of variability in the values of σ_A and σ_E even though a prediction scheme for these quantities, based upon synoptic meteorological data, is not available. The enhancement of σ_A and σ_E due to the mechanical turbulence effect of airflow over a built-up urban area along the coastline varied between a factor of 2 and 10 during the observation periods. By comparison, Slade (1962) and Markee (1963) found an average decrease of 50% in the values of σ_A for over-water flow compared to over-land flow in the Chesapeake Bay region. Munn (1964) also found marked differences in σ_A and σ_E for data collected at a lakeside location compared with similar data from a second station located approximately 10 miles inland.

Significant differences in the σ_A and σ_E values between the bow and mast were observed often during this study. Bow data at approximately 3 meters above the water surface are influenced by water wave-induced turbulence more frequently than are mast data.

A ship-based turbulence observation program has two advantages relative to observations at fixed locations: First, the same observing equipment is moved from site to site so that all data are derived from the same set of transducers and the exposure of the transducers to the ambient atmosphere remains fixed throughout the observing period. Comparisons of data sets generated by multiple equipment installations suffer from variances in the calibration of the instruments and differences in exposure of the wind sensing devices. Second, instrumentation cost is reduced because only one set is required for the entire program.

Two major disadvantages of a ship-based observing program are: First, the observing platform (the ship) is not fixed and the ship's motions appear in the wind data as error signals although this effect is not important for observations of wind changes with periods longer than about 10 seconds. Second, it is impossible to obtain simultaneous observations at multiple sites.

III. Estimated shoreline concentrations of airborne products from off-shore incineration.

A. Estimates of plume parameters based upon meteorological data.

To analyze the risk of high concentrations of incinerator products in the atmosphere along the coastline, it is necessary to convert the observations of atmospheric turbulence into descriptions of diffusion parameters. This is the problem of converting fixed position wind speed fluctuation data (the Eulerian description) into estimates of diffusion following the motion of the effluent (the Lagrangian description).

For this analysis the Gaussian plume model in common use (Gifford, 1961; Pasquill, 1961; Turner, 1969) has been adopted. The concentration downwind (along the x-axis) from an elevated, continuous point source at (0,0,H) in an (x,y,z) coordinate system is given by

$$\chi(x,y,z;H) = \frac{Q}{2\pi\sigma_y\sigma_z u} \exp\left(-\frac{1}{2}\frac{y^2}{\sigma_y{}^2}\right) x$$

$$\left\{ \exp\left[-\frac{1}{2}\frac{(z-H)^2}{\sigma_z{}^2}\right] + \exp\left[-\frac{1}{2}\frac{(z+H)^2}{\sigma_z{}^2}\right] \right\} \qquad (1)$$

where

H = effective height of emission (meters)

Q = source strength (grams/sec)

σ_y = measure of the lateral spread of the plume (meters)

σ_z = measure of the vertical spread of the plume (meters)

u = mean wind speed (meters/sec).

This equation describes the time-averaged behavior of a steady-state effluent plume which is assumed to be transported by the local wind. (The time averaging period can be assumed to be 10 minutes). The centerline of the plume is assumed horizontal and no fallout of plume material is described by this equation.

The cross-plume and vertical spread measures (σ_y and σ_z) are generally related to downwind distance and to atmospheric stability.

For the present analysis, these measures are derived from the wind observations previously discussed.

Several authors have discussed conversion of observed wind fluctuations (σ_A and σ_E) to the plume forms (σ_y and σ_z). Hay and Pasquill (1957) reported, from the results of dispersion experiments involving Lycopodium spores, good agreement between σ_E as measured at the release point and σ_z (in angular units) as measured by the vertical distribution of spore concentrations. These experiments involved travel distances of less that one kilometer and the ratio σ_z/σ_E was nearly unity for eight trials. Cramer (1957) reported a good relationship between cloud widths 100 meters downwind from a smoke source and σ_A data for experiments over flat land and in hilly terrain. When Cramer's data are converted to the ratio σ_y/σ_A, the values of this parameter are also near unity. Islitzer (1961) derived the relationship $\sigma_A\ x = 1.23\ \sigma_y$ from fluorescent tracer observations up to approximately two kilometers downwind from an elevated, continuous source. (For the calculation of σ_A, 5 second average wind direction data were used.) In summary, Pasquill (1962) suggested that a simple relation between plume spread and observed velocity fluctuations is implied by the available field data, particularly for travel distances no longer than a few kilometers. The relationship is least valid during very stable conditions and for vertical spread of plumes near the surface of the earth.

For the calculations discussed below it has been assumed that the plume spread (in angular units) is approximated by the measured wind fluctuations σ_A and σ_E. Ten second average wind data are used because they are relatively free from the influence of the boat's motion but retain wind perturbations having periods significantly less than one minute.

B. A conservation calculation of maximum shoreline concentrations

A maximum risk calculation for shoreline concentrations of particulates resulting from offshore, high volume incineration indicates that, even for the poorest mixing conditions, projected shoreline concentrations will be acceptably low for incineration at a distance of 10 kilometers offshore.

The parameters adopted for the calculation are summarized in Table 6-2. An incinerator charging rate for 3 units is taken as 100 tons/hour; concentrations expected from other charging rates can be scaled directly from this figure. The particulate emission rate (0.1%) is taken as representative of emissions from well-designed incinerators having settling chambers but no collection equipment such as precipitators or scrubbers. The wind spread data are taken as representative minimum values from the observations described in the previous section. The wind speed is the lowest value which might be expected for a sustained onshore flow pattern (2 meters/sec = 4.5 mph, approximately). The offshore distance of 10 kilometers is a reasonable minimum distance for the initiation of incineration in the proposed operation. If necessary, the start-up could be postponed until offshore distances of 20 to 30 kilometers were reached.

From the Gaussian plume formulation described in equation (1), the plume boundaries (including 95% of the effluent) can be

TABLE 6-2

Parameters used in conservative calculation of shoreline particulate concentrations.

PARAMETER	VALUE
Incinerator charging rate	100 tons/hour (= 25.2 kg/sec)
Particulate emission rate	0.1% of charge (i.e. 1 lb/1000 lb charged)
Vertical wind spread	$\sigma_E = 1.0°$
Horizontal wind spread	$\sigma_A = 5.0°$
Mean horizontal wind speed	$u = 2.0$ meters/sec
Offshore distance	$x = 10$ kilometers
RESULT OF CALCULATION	
Average concentration at shoreline	$\chi_{AVE} = 16.5$ μgm/meter^3 in a plume approximately 3.5 kilometers wide

taken as $2\sigma_y$ (in length units) on both sides of the plume centerline. If the effective emission height is assumed to be the ocean surface, (which leads to the maximum concentration estimate) the average ground level concentration within the plume at the shoreline will be

$$\chi_{AVE} = \frac{\sqrt{2}}{4\sqrt{\pi}} \frac{Q}{\sigma_y \sigma_z u} \tag{2}$$

The plume spread parameters are evaluated as

$$\left.\begin{aligned} \sigma_y &= \sigma_A\, x \\ \sigma_z &= \sigma_E\, x \end{aligned}\right\} \tag{3}$$

where σ_A and σ_E are measured in radians. Therefore

$$\chi_{AVE} = \frac{\sqrt{2}}{4\sqrt{\pi}} \frac{Q}{\sigma_A \sigma_E x^2 u}$$

$$= \frac{\sqrt{2}}{4\sqrt{\pi}} \frac{(25.2\text{ gm/sec})\ (57.3°/\text{radian})}{(5°)(1°)(10^8 m^2)\ (2m/\text{sec})} \tag{4}$$

$$\chi_{AVE} = 16.5\ \mu gm/m^3 \text{ at shoreline}$$

Also $\quad$ Plume width $= 4\sigma_y = 4\sigma_A x = \dfrac{4(5°)(10^4 m)}{(57.3°/\text{radian}}$

$= 3.5$ kilometers at shoreline.

The estimate of 16.5 $\mu gm/m^3$ as the maximum expected shoreline concentration represents an upper limit value which would occur only infrequently in practice. When atmospheric conditions suggest this larger estimate, incineration could be deferred until larger offshore distances are reached. Because of the inverse square relationship between plume travel and concentrations, the predicted shoreline concentration can be reduced by nearly an order of magnitude if incineration occurs 30 kilometers offshore. At larger offshore distances the probability of very light winds is reduced and a greater initial dilution of the plume would be expected.

The calculation summarized here does not recognize the fall-out of the larger particulate material from the plume. Thus, expected mass concentrations at the shoreline are overestimated.

C. Conclusions based upon the dispersion calculations

Over the ocean, as over land, a well designed incinerator will not seriously affect neighbors at distances greater than one kilometer. Although the average atmosphere dispersion capacity is less over water than over land, this difference does not result in significant concentrations at distances several kilometers downwind from the incinerator emission point.

The calculations summarized above suggest the following interpretations.

During the most unfavorable conditions, concentrations caused by incineration ten kilometers offshore would be less than 20 μgm/meter^3. Current standards for total suspended particulates in Massachusetts are 65 μgm/meter^3(maximum annual average) and 160 μgm/meter^3 (maximum 24-hour concentration). During steady, onshore wind conditions, the air entering the urban area generally exhibits low concentrations of particulates; thus the maximum contributions from offshore incineration should never result in concentrations in excess of the standards.

Most of the time when onshore winds occur, incineration at ten kilometers offshore would result in concentrations of less than 5 μgm/meter^3 at the shoreline.

Offshore winds occur more frequently than onshore flows for coastal cities along the eastern seaboard of the United States. Onshore winds occur in Boston approximately 25% of the time, on an annual basis. (Climatic Atlas of the United States, 1968). Therefore, the annual average "loading" of concentrations in the urban coastal atmospheres, caused by offshore incineration, would be negligible.

Using particulate concentration as an appropriate index of air quality, an operational scheme for incinerator operation satisfying air pollution constraints might be:

1) When offshore winds occur, incineration can begin as soon as the vessel clears the harbor region.
2) When onshore winds occur, incineration can begin at a distance of ten kilometers from expected landfall for the plume, unless the wind speed is less than 5 mph.
3) When light (<5 mph) onshore winds occur, incineration can be delayed until a twenty kilometer offshore distance is reached. (This constraint will probably prove unnecessary in practice.)

IV. Operational constraints associated with adverse weather conditions.

The proposed ocean based disposal system is subject to interruption during periods of severe weather. The frequency of such interruptions depends upon many factors, including system configuration (ship or towed barge), vessel size and shape, design of incinerator and materials disposal equipment, available navigational aids, and job functions for the operating manpower. The meteorological parameters chosen to describe adverse conditions include wind, temperature, precipitation and fog.

High wind conditions represent the most obvious risk for the disposal operation. Sea state is related to local wind speed and high winds are usually accompanied by adverse wave and swell conditions. For a self-propelled incinerator ship having dimensions of a World War II Liberty ship, a sea state associated with 30 knot (34.5 mph) winds normally will not prevent safe operation of the vessel (U.S. Coast Guard, private communication). However, if incinerator operation or waste discharge procedure is sensitive to ship roll, a lower safe wind might be required.

If the incinerator is installed on a vessel which is towed to the disposal site, the wind constraint is more restrictive. Management of a barge of ship hull by a towing vessel is difficult during high sea conditions and it may be necessary to restrict operations whenever the local winds exceed 20 knots (23 mph).

This safety constraint is particularly important if the system operating plans require manpower transfer between the towing vessel and the barge. However, during high wind conditions it may be possible to burn in the outer harbor inlet or islands without exceeding permissible ground level constraints at the shore.

Low temperatures would restrict the disposal system operation if they prevented normal operation of shipboard equipment or if exposure constituted a health and safety risk for the operating personnel. The cold exposure risk, for both men and materials, is a function of air temperature and wind speed. A nominal operating constraint might be taken as: (1) wind speed in excess of 20 mph and temperature below 15°F, or (2) temperature below 0°F with any wind speed.

Precipitation would not normally interrupt operation of the ocean disposal system although exceptional cases might occur. For example, freezing rain might interfere with the operation of waste transfer mechanisms from ship storage to the incinerator. As precipitation is frequently associated with organized storms (i.e., low pressure systems) disposal system disruption during precipitation periods would be more likely caused by concurrent wind and temperature conditions.

Fog might constitute a navigational safety constraint for the disposal vessel but if it is equipped with good navigational aids (radar, LORAN, bottom sounding equipment, multichannel radio transmitter and receiver), sea operations need not be restricted.

However, operation within the harbor and docking region may be impeded by fog, particularly for a towed vessel operation.

Table 6-3 summarizes possible operating constraints. These values are suggested for the purpose of meteorological and climatological analysis. For a specific system, it would be necessary to develop relevent operating constraints from detailed engineering and operating data.

TABLE 6-3

Possible meterological limits for the operation of an ocean based waste disposal system

Self-Propelled Incinerator Ship System

1. Wind exceeding 35 mph.
2. Temperature below 15°F and wind exceeding 20 mph.
3. Temperature below 0°F, any wind.
4. Heavy fog.

Towed Incinerator Vessel System

1. Wind exceeding 23 mph.
2. Temperature below 0°F.
3. Heavy fog.

The constraints proposed in Table 6-4 have been investigated for the Boston region using available climatological data (U.S. Dept. of Commerce, ESSA, 1968; 1969). Annual average wind speed data are summarized in Table 4. For a self-propelled ship, the high wind constraint would be invoked less than one percent of the time. For a towed vessel operation, high winds might prevent operation during 8 to 10% of all days. Thus, the towed barge operation is not attractive, unless the wind speed constraint can be relaxed for the proposed system, or unless incineration can be carried out within the Harbor region on windy days.

TABLE 6-4

Annual frequency of wind by speed groups for Boston (from U.S. Dept. of Commerce, ESSA, 1968)

Wind speed group (mph)	Percentage frequency
0 - 3	3
4 - 7	12
8 - 12	33
13 - 18	35
19 - 24	12
25 - 31	4
32 - 38	1
39 - 46	0
>47	0

The minimum recorded temperature at Boston for a five-year record period is -4°F. Thus the low temperature constraint would not affect the disposal system operation significantly. The combined wind and temperature constraint for the ship system would be invoked approximately one percent of the time; therefore it does not prevent the operation of the proposed system.

Heavy fog occurs in the Boston Harbor region approximately two days each month (U.S. Dept. of Commerce, ESSA, 1969). However, the duration of the fog is usually limited to a few hours at a time. Thus, ship operation would not be significantly affected unless a specific departure time had to be maintained each day. (Heavy fog most frequently occurs over the ocean during the nighttime and early morning, with dissipation during the day. Thus early morning ship departures might be delayed as much as 5% of the time).

In addition to examining the frequency of occurrence of adverse weather conditions, it is necessary to investigate the persistence of poor weather. Weather restrictions upon the disposal operation can be tolerated for a small percentage of the time. When adverse weather continues for periods of several successive days, the accumulation of unprocessed wastes require extra, and costly, storage capacity at dockside or at some intermediate location.

The only weather pattern likely to cause persistent interruption of the disposal operation in the Boston region is a northeast storm which loses its forward motion in the vicinity of the New England Coast. Such storms occur from two to five times annually, but they usually cause high winds in the Boston region for no more than two days. A "three day storm" occurs approximately once each year, and a "four day storm" usually occurs only once each few years. Thus "persistent restrictive conditions" occur with sufficiently low frequency that they do not constitute a prohibitive constraint upon the proposed system. When a persistent storm occurs in the winter months, the waste pick-up system is often interrupted while the collection vehicles are used for snow removal. During this period, the flow of wastes to a dockside location is likely to be reduced or eliminated and wastes would normally be stored at site of generation for a number of extra days.

In summary, an incinerator ship system would be interrupted by adverse weather conditions only about 1 to 3% of the time (i.e., 3 to 10 days annually). Successive interrupted days would occur from time to time, but these persistent conditions would not prohibit the long term operation of the ocean disposal system. A towed barge operation might be interrupted by high winds (and the associated high seas) as much as ten percent of the time (35 days per year), and such interruptions might be unacceptable for a proposed system. These estimates are reasonable, but they may change significantly for a specific system. If the estimates are inaccurate, they would likely change in the direction of more relaxed restrictions.

V. Background concentrations of pollutants in the Boston region.

During the period of this study, a limited program of air sampling was carried out at the Harvard School of Public Health. Smokeshade was the principal measurement and these data provide information concerning the typical variability of dust loadings in the Boston atmosphere. Based upon approximately eighteen months of observation, three conclusions can be cited:

1) Hour-to-hour and day-to-day variability in smokeshade is controlled primarily by the synoptic scale meteorological pattern.
2) The long term (i.e., monthly) average pattern of daily variability is a two-peaked distribution. On the average, maximum daily particulate concentrations occur at approximately 8:00 am. Concentrations decrease during the morning and early afternoon, and a secondary maximum occurs 6:00 to 10:00 pm. Minimum concentrations on a typical day occur in the hours before sunrise. This pattern has been observed in many other cities. It reflects the average daily variability in atmospheric mixing height and, to a lesser extent, the average daily variability in emissions.
3) Maximum readings occur during the winter months. Average summer observations of smokeshade are less than one half of the winter values.

These background observations were obtained to investigate the occurrence of periods of maximum particulate concentration in the Boston atmosphere to determine if it would be necessary to impose more restrictive air pollution constraints upon the disposal system operation during high concentration periods.

However, the expected shoreline concentrations caused by offshore incineration are so low that additional constraints are probably unnecessary and, in addition, the daily smokeshade readings are so variable that short term forecasts of atmospheric particulate loadings are not likely to be a useful input to the operating parameters for the disposal system. Figure 6-14 illustrates the patterns observed on four typical, successive days. Much of the indicated variability is obviously related to short period changes in local meteorological parameters.

Forecasts of long stagnation periods that might result in high pollutant concentrations could be used as constraints upon the selection of offshore incineration sites. Air Pollution Potential Forecasts are prepared by the National Air Pollution Control Administration for the 48 contiguous states and are available from local Weather Bureau (ESSA) offices.

Figure 6-15 illustrates average daily smokeshade readings for each of the winter months of 1966-67. Only weekday data were used to prepare these averages. Patterns are significantly different on the weekends. The two-peaked daily pattern shown for each month in Figure 6-15 was obtained for all months during the study period.

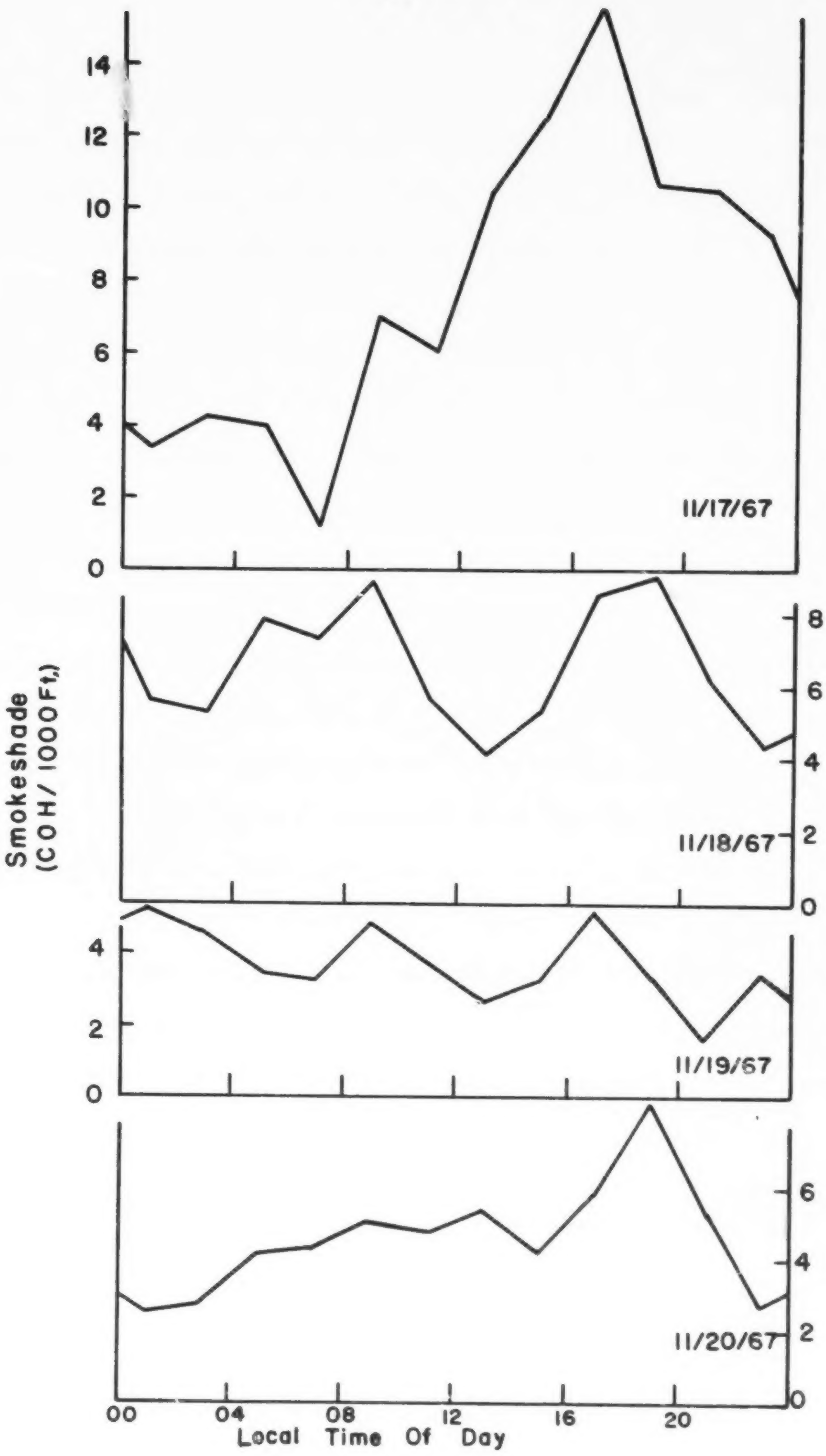
VI. General statement of conclusions.

METEOROLOGICAL DATA

(Collected for the analysis of turbulent dispersion rates over the ocean)

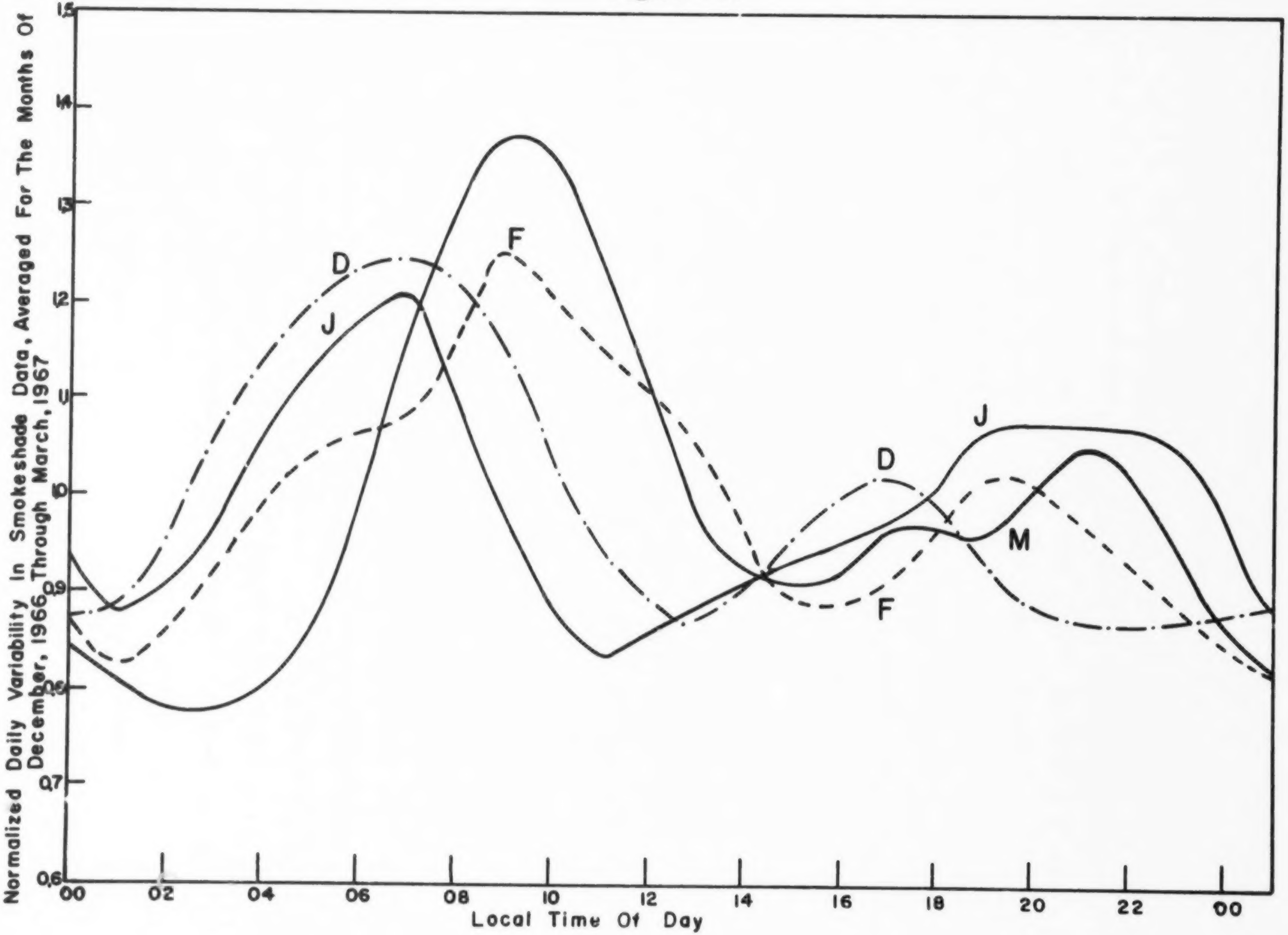
1) Atmospheric dispersion rates over open water are typically less than one-half those occurring simultaneously over built-up land areas.

Figure 6-14



Smokeshade observed at the Harvard School of Public Health during four consecutive days. The variability in levels is related primarily to changes in synoptic weather conditions during the period.

Figure 6-15



Normalized Daily Variability In Smokeshade Data, Averaged For The Months Of December, 1966 Through March, 1967

Sometimes dispersion rates over water are as low as one tenth simultaneous values over land.

2) The change from overland to overwater dispersion rates usually occurs within a distance of two kilometers offshore for westerly winds in the Boston Harbor region.

3) Day-to-day variability in overwater dispersion rates is very large. The data set collected during the field experiments is insufficient for the development of a regression equation relating dispersion rates to predictors such as wind speed, fetch, atmospheric stability and sea state. The great variability in the observed data suggests that no significant regression relationship could be derived with a larger data set.

4) Significant vertical variability in observed dispersion rates (i.e., variability in wind fluctuations at bow and mast height) was noted frequently. This suggests that two or more wind observing systems should always be used during field experiments aimed at determining local dispersion patterns.

ESTIMATES OF CONCENTRATIONS AT SHORELINE DUE TO OFFSHORE INCINERATION

1) During very unfavorable atmospheric conditions (light, steady, onshore winds), incineration of 100 tons/hour of waste 10 kilometers offshore might result in concentrations of 20 μgm/meter^3 along a few kilometers of shoreline.

2) Most of the time these operating conditions would result in concentrations of less than 5 μgm/meter^3 along the shoreline.

3) It appears that incineration can proceed safely within 20 kilometers of shoreline even with very restrictive air quality constraints.

OPERATIONAL CONSTRAINTS DUE TO ADVERSE WEATHER CONDITIONS:

1) A self propelled incinerator ship might be interrupted due to adverse weather (high winds, heavy fog) approximately 1 to 3 percent of the time. Approximately once a year, a continuous interruption of two or three days will occur.

2) A towed vessel disposal system might be interrupted as frequently as 10 percent of the time unless incineration can be carried out at sheltered locations on windy days This estimate is conservative (i.e., high) and might be lowered when specific design data are available.

BACKGROUND CONTAMINANT CONCENTRATIONS IN THE URBAN AREA

1) The contribution of offshore incineration products to the typical urban atmospheric pollutant load would be negligible. Therefore, the time scheduling of the disposal operation need not be restricted by the time variability of concentrations in the urban atmosphere.

2) During forecast periods of atmospheric stagnation accompanied by persistent on-shore winds, offshore incineration within 10 miles (as well as many other operations resulting in pollutant emissions) might be suspended temporarily.

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SECTION 7

A SIMULATION MODEL FOR SOLID WASTE MANAGEMENT

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7-1

A SIMULATION MODEL FOR SOLID WASTE MANAGEMENT

by

Frances Grommers
James Mahoney
Melvin First

I. INTRODUCTION

This paper presents a waste management simulation model to be used as a decision aid when planning the use of combined land and ocean based disposal methods. The model simulates combinations of disposal options and, based upon cost and benefit estimates, computes resulting net cost of these options to the community. The model also computes the amounts of scarce resources such as manpower required by the different combinations. The planner can rank and compare the different combinations by these criteria, and use this information to aid in making necessary planning and management choices.

For many complex urban systems such as waste disposal it is important that net benefit to the community be the ultimate decision criterion. The principal benefit resulting from any combination of options that disposes of all waste is the same in every case: i.e., the value to the community of prompt total disposal of all waste generated. Secondary benefits which may result from waste disposal include land recovery at landfill sites and useful heat generation by waste incinerators. These benefits, if sufficiently large compared to the cost, may be critical at the margin in the choice among combinations of disposal methods and, moreover, may represent many millions of dollars to the tax payer over a long period.

Since the value of the principal benefit is the same for each combination of disposal methods that disposes of all the wastes generated, alternative plans can be ranked by a net cost figure defined as the algebraic sum of all costs and benefits to the community of the waste disposal system without including the unchanging principal benefit in the calculation. On this basis, for each plan, net cost differs from total net benefit by the same quantity, i.e., the value to the community of the absence of waste.

A. Simulation Models

Mathematical models have been used to solve deterministic planning problems when the number of variables is small. However, a metropolitan solid waste disposal system is stochastic, has at least two hundred variables, and includes some allocation and scheduling problems which have no mathematical solution. Kuehn and Hamburger(1) discussed the difficulties in applying mathematical models to problems with large numbers of variables and described a hueristic analytic method for the solution of a warehouse location problem which involves about 40 variables; near the upper limit of the number of variables it is possible to handle with current computers.

When mathematical and computer technology cannot be used to produce an optimum plan for a system as large, complex, and non-linear as a solid waste disposal system, a simulation model can be prepared to explore alternative policy decisions which are made by metropolitan solid waste disposal system authorities. By this means, meaningful results can be obtained even with incomplete data.

A valid simulation model incorporates all significant relationships affecting the objectives of the system so that changes in model variables produce the same effects on the model output as comparable changes produce in the real system. After validation of model performance by comparison with the real system, the model can be used as a substitute or supplement for field trials. The model can also be used to evaluate the sensitivity of the system to changes in specific variables and to estimate their relative importance. This will limit investigation and save money when field trials must be made. The model can be used to discover tradeoffs between policies and to anticipate the effectiveness of alternate actions.

In addition to using a simulation model to evaluate results of proposed changes in system elements and operating rules, the results of coordinated series of incremental changes can become an important aide when searching for optimal system designs. This was demonstrated by Maass et al.(2) who described a statistical sampling method for approaching an optimum system design using a simulation model of a simplified water resource system.

B. Solid Waste Disposal Methods.

1. Land based methods

Most urban solid waste is currently disposed of by incineration (with removal and burial of the residue and other incombustible wastes) or by burial at landfill sites without prior treatment. The cost for incineration is high, often exceeding $5.00 per ton of waste,(3) and operation of incinerators in urban areas can cause local air pollution and odor nuisance problems.

Waste disposal by modern sanitary landfill methods is preferable whenever appropriate sites are available because costs are lower than for incineration (about $2.00 per ton for large scale operations),(3) and the possibility of local air pollution is minimized. However, appropriate landfill sites are being rapidly filled to capacity in many cities and new sites at reasonable haul distances are difficult to obtain because they are outside the political boundaries of the core city.

2. Ocean based incineration and disposal

Ocean based disposal requires a ship fitted out with high capacity, high temperature incinerators and equipment capable of discharging non-floatable residue from the incinerator to well below the water surface. Important steps in an operating routine for such a ship include:

1. Charging the ship's solid waste storage holds from trucks or a holding silo at dockside; or loading the waste collections as containerized loads.
2. Initiating incineration at a safe distance from shore to avoid an air pollution risk for the coastal area.
3. Discharging the hot, well-fired inorganic residue to a quench and settling tank where floating material (largely charred wood fragments and cans) is crushed, dewatered, and recharged to the incinerator.
4. Discharging the non-floating residue (approximately 98% of the total) well below the water surface when the ship reaches a designated dumping area.
5. Returning to dockside after all the solid waste is incinerated to repeat the cycle.

Associated studies of the incinerator ship concept include:(4)

a) Observations of the stability of typical incinerator residue deposited on the ocean bottom.

b) Investigations of toxic effects of incinerator residue on commercially important fish, particularly hard shell clams and bottom dwelling flounder, larval forms of lobsters and similar species, and the plankton on which they feed.

c) Evaluation of the risk of air pollution in coastal areas caused by incineration at near-shore locations and the delineation of acceptable burning areas for every weather pattern that is safe for ship operation. An associated study is a prediction of the frequency and duration of foul weather periods when an incinerator ship cannot put to sea with safety.

II. THE SIMULATION MODEL FOR METROPOLITAN BOSTON

A. Model Rationale

1. Objectives

The objective of the Boston waste disposal system is considered to be complete disposal of all waste produced. In the process, maximum recovery of valuable scrap, utilization of heat produced by incineration, and creation of new land from raw waste or incinerator residue produce desirable benefits. Constraints include control of incineration to meet air pollution abatement requirements and regulation of landfill usage to preserve some land for disposal during periods when incineration is impossible because of mechanical failures or prohibited because of prolonged air stagnation or violent storms at sea.

2. Economic Factors

For purposes of model development, the major costs of a waste disposal system were considered to be: cost of collection and hauling to final disposal sites (80% of the total disposal cost in some communities); cost of land-based incineration and residue burial; cost of sanitary landfilling; cost of ship incineration and disposal of non-floating residues in the ocean; air pollution damage from individual or public disposal by incineration. Major secondary benefits were considered to be: heat recovered from the incineration process; new land created by filling operations; and increased revenues from the fishing industry because of the beneficial effects on fish reproduction of reefs created by ocean bottom disposal of incinerated residue and large, non-combustible metal and mineral objects.

3. Systems variables

A model was designed to represent the entire waste disposal system which interrelated the following subsystems: waste disposal methods; by-products of disposal procedures (e.g., air pollution, new land production, heat production); weather, labor costs;and equipment costs.

Systems variables included:

a) size and location of the collection sheds
b) capacities of intermediate and dock storage facilities
c) locations of intermediate and dock storage facilities

d. transfer schedules

e. truck capacities used to haul waste to intermediate storage and from intermediate storage to dockside.

f. incinerator ship operating schedules.

Part A of Table 7-1 lists primary independent variables. Part B lists secondary variables, and Part C lists all operating parameters.

B. Cost and Benefit Functions

Sixteen cost and benefit functions represent estimates of the dollars, per ton of waste, expended or created by various major steps in the disposal process. These major steps are identified in the context of a materials flow summary, beginning with the generation of the waste material. In Figure 7-1, a schematic display of the summary cost categories are enclosed within boxes and benefits are indicated by parentheses.

Full evaluation of each cost category results in a total list of several hundred items which affect the system cost to some degree. Such a detailed analysis is not required in the present study which seeks to aid in maximizing net benefit as a result of carefully planning the major factors subject to control by the authorities.

The cost and benefit functions which follow were derived principally from figures supplied by the Boston Department of Public Works(5) for 1961-1965, the University of California Sanitary Engineering Research Project,(3) and the American Public Works Association.(6,7) Some values are hypothetical but of the right order of magnitude and were chosen for ease of error detection and debugging of the model. Other (real time) values may be substituted without changing the logic of the program. Benefits were given nominal dollar values to represent their contribution as non-zero. The benefits have not been specifically evaluated for Boston and would probably be higher than the values selected. To apply this model to a metropolitan area other than Boston, a new economic and events flow analysis must be performed.

An explanation of the 16 functions follows:

Function 1 is the daily additional cost of air pollution in dollars(8) per ton of waste disposed of by individual incineration as a function of allowable air pollution (indicated by an air pollution index target) and the tons processed daily (t/d). The first column ($/t) values represent overhead for equipment when no waste is processed that day. Note that the cost of controlling air pollution is higher at high tonnages, when the design capacity of the incinerators is reached or exceeded.

PPM-SO_2 Index	-1 t/d	2-1000 t/d	1001-2000 t/d	2001-3000 t/d	3001-4000 t/d
	$/t	$/t	$/t	$/t	$/t
< 0.05	1.00	2.00	5.00	6.00	7.00
0.05-0.10	1.00	1.75	4.00	5.00	6.00
> 0.10	1.00	1.50	2.00	4.00	5.00

The figures in the table are estimates. Different values may be introduced into the model without reprogramming.

Function 2 is the cost of public collection per ton of waste as a function of the projected five-yearly increase in labor costs which will probably rise with the projected rise in cost of living.

Years of Series	1-5	6-10	11-15	16-20	21-25
Cost ($/ton)	10.00	11.00	12.00	13.00	14.00

Function 3 is the cost of private collection per ton of waste as a function of the projected rise in labor costs and has been set identical to Function 1 for ease of program development. Other values may be substituted.

Function 4 is the cost of trucks to haul wastes from collection areas to intermediate storage sites as a function of the projected five-yearly increase in the capital, operating, and maintenance cost of trucking.

Years of Series	1-5	6-10	11-15	16-20	21-25
Cost ($/ton)	15.00	17.00	19.00	21.00	23.00

Function 5 is the cost of manpower on the haul from collection sites to intermediate storage sites as a function of increased labor costs projected over 5-yearly intervals.

Years of Series	1-5	6-10	11-15	16-20	21-25
Cost ($/man hour)	3.00	4.00	5.00	5.00	5.00

The total hauling cost of moving waste from collection sites to intermediate storage and transfer sites is determined by the information contained in the tables associated with Functions 2, 3, 4, and 5 plus total tons collected, travel time, truck capacity, number of working hours per day, number of men and trucks available, truck operating costs, and wage rates. In the model, each of these rates may be varied independently and simultaneously by the investigator. A change in one of these variables will alter the contribution to the total cost (and the net benefit) in a predictable manner but when changes occur in two or more variables, it is not clear *a priori*, in which direction the net benefit will move.

Function 6 is the cost, in dollars per ton, of processing waste at an intermediate storage and transfer site as a function of physical storage capacity and the number of tons stored daily. The first column figures represent overhead for a facility built but not used. $1000 per ton represents the cost if the maximum storage capacity is exceeded by 100%. This value is placed excessively high so that this allocation of waste to the transfer station, non-feasible in reality, will be signalled by the program as excessively expensive. The purpose of intermediate storage is to provide for accumulation of wastes and later transfer to large capacity vehicles that can complete the movement to a disposal site at less cost than moving the waste to a distant site by the collection vehicles and pickup crews.

Function 2 is the cost of public collection per ton of waste as a function of the projected five-yearly increase in labor costs which will probably rise with the projected rise in cost of living.

Years of Series	1-5	6-10	11-15	16-20	21-25
Cost ($/ton)	10.00	11.00	12.00	13.00	14.00

Function 3 is the cost of private collection per ton of waste as a function of the projected rise in labor costs and has been set identical to Function 1 for ease of program development. Other values may be substituted.

Function 4 is the cost of trucks to haul wastes from collection areas to intermediate storage sites as a function of the projected five-yearly increase in the capital,operating,and maintenance cost of trucking.

Years of Series	1-5	6-10	11-15	16-20	21-25
Cost ($/ton)	15.00	17.00	19.00	21.00	23.00

Function 5 is the cost of manpower on the haul from collection sites to intermediate storage sites as a function of increased labor costs projected over 5-yearly intervals.

Years of Series	1-5	6-10	11-15	16-20	21-25
Cost ($/man hour)	3.00	4.00	5.00	5.00	5.00

The total hauling cost of moving waste from collection sites to intermediate storage and transfer sites is determined by the

Tons Stored Daily	0-1 t/d	2-100 t/d	101-500 t/d	501-1000 t/d	1001-2000 t/d	2001-3000 t/d	3001-4000 t/d
Capacity < 1000 tons	1.00	0.50	0.50	0.50	0.20	1000.00	1000.00
1000-2000 tons	1.00	0.60	0.60	0.40	0.30	0.20	1000.00
> 2000 tons	1.00	0.70	0.70	0.70	0.40	0.30	0.20

Function 7 is the cost of sanitary landfilling per ton of waste as a function of the daily capacity at the landfill site.(3)

Capacity: (tons)	30	100	200	500	1000	1500	2000	3000	4000
Cost ($/ton)	5.72	2.88	2.32	2.03	1.90	1.86	1.82	1.80	1.77

The fee to users of the sanitary land fill, and thus their contribution to the total net cost of the waste disposal system, depends upon the objectives and constraints imposed by and upon the waste disposal authorities. For example, when the authorities desire to use filled land at the earliest possible date, the user's cost for filling may be set low, perhaps equal to the labor costs required to handle the incoming waste. However, if 25% of the land must be preserved for emergency use, the cost of filling can be increased until the rate of use of the landfill site is reduced to the desired level. Relaxing this constraint, by allowing 90% of the land to be used up at will, would imply a lower cost to the users. Function 8 is the benefit per ton of waste sent to a landfill site as a function of the sale value of the usable land created.

A value of 4000 tons of compacted waste seven-feet deep was assumed equivalent to one acre of new land. The dollar values are nominal, used to develop the model, but any other values may be substituted without changing the program. For example, **two million** dollars an acre would be a realistic land value in the center of the city of Boston, whereas land on the outskirts may bring only a few thousand dollars per acre.

Sale Value ($/acre)	0.0	1.0	1000	2000	4000
Benefit ($/ton)	0.0	0.1	0.25	0.50	1.00

The dollar benefits per ton of waste disposed of by landfill methods depend upon the uses to be made of the filled land. As earlier use of the filled land may be more valuable to the community than later use, the benefit realized may be greater when the site is filled at a more rapid rate. The marginal utilities of new land, obtainable early or late, and of unused land determine the relative contribution that each unit of sanitary landfilling makes to the present value of the total net cost of the waste disposal system. Function 9 is the cost per ton of waste incinerated as a function of the daily rated capacity of the incinerator under full load.(3)

Capacity (tons/day)	100	240	600	900	1200	2400
Cost ($/ton)	7.70	6.22	4.70	4.57	4.50	4.18

As a practical matter, incinerator operating cost varies with the percent of full capacity utilized but this factor was not included in the calculation.

Function 10 is the benefit per ton for usable heat production at a land-based incinerator as a function of the cost of heating oil not required to meet expected demand. When heat is recovered from waste incineration and a contract is entered into to provide utility service on a demand basis, e.g., to meet the heat, hot water, and process steam requirements of a hospital, the unit cost of incineration will reflect the cost of supplementary fossil fuel that must be purchased when the total heat demand cannot be met from waste burning alone. Therefore, the program credits landbased incineration with the cost of fossil fuel not required to meet full load conditions because of the substitution of an equivalent heating value with solid waste. The maximum daily benefit from waste heat recovery is limited by the total amount of heat required as the value drops to zero when the maximum capacity of the hospital for accepting heat and steam is reached. The use of the index numbers in the table instead of actual oil costs allows a decision maker to evaluate the effect on net cost of several grades of oil at different prices. The index can be changed by altering program starting values.

Oil Cost Index	1	2	3
Benefit ($/ton)	0.10	0.15	0.20

Function 11 is the cost per hour of trucks on haul from intermediate storage to dockside for ship incinerator disposal as a function of the projected 5-yearly increases in the cost of truck operation.

Years of Series	1-5	6-10	11-15	16-20	21-25
Cost ($/hour)	20.00	22.00	24.00	26.00	28.00

Function 12 is the cost per hour of men hauling from an intermediate storage site to the dock as a function of projected 5-yearly increases in labor costs.

Years of Series	1-5	6-10	11-15	16-20	21-25
Cost ($/man hour)	5.00	6.00	7.00	7.00	7.50

Trade-offs exist between intermediate storage capacity, haul distance between intermediate storage and dock storage, dock storage and transfer truck capacity, and ship schedule. The ratios of their marginal utilities govern their collective effects on net cost.

Function 13 is the dollar cost per ton of dockside storage as a function of storage capacity and tons stored daily. These values are estimated and set at the same range as those for intermediate storage.

Tons Handled Daily*	< 100	101-500	501-1000	1001-2000	2001-3000	3001-4000
Design storage capacity	$	$	$	$	$	$
< 1000 tons	0.50	0.50	0.50	0.20	0.20	0.20
1000-2000 tons	0.40	0.40	0.40	0.20	0.20	0.20
> 2000 tons	0.30	0.30	0.30	0.20	0.20	0.20

*Tons handled daily may exceed design storage capacity when storage areas are filled and emptied more than once per day.

Function 14 is the cost of incremental dockside storage attributable to bad weather as sometimes inclement weather conditions interfere with collecting and processing of waste and an incinerator ship may be prevented from loading, entering, or leaving port. The number and sequence of such days influences the amount of dockside storage required.

Additional* tons handled daily	0	1-10,000
Cost ($/ton)	0	1.00

*In excess of maximum dockside storage capacity at time of computation.

Function 14 has been included to indicate frequency of storage under capacity and the cost of providing specific increments of storage capacity above the amount specified by the Function 13 table. Dollar values have been assigned for ease in debugging the model, i.e., when 0 tons were stored, no overhead cost was assigned since this function was added only to determine the cost of excess storage required, in the case of bad weather, as explained in Section C2 below.

Function 15 is the cost of shipboard incineration(9) as a function of the rated daily capacity of the incinerator ship.

Capacity (tons/day)	100	240	600	900	1200	2400
Cost ($/ton)	7.70	6.22	4.70	4.57	4.50	4.18

Ship incineration costs were set identical with land incineration costs but additional calculations, based upon different estimates of ship costs, were carried out as well. These are discussed in Section III.

Function 16 is the benefit from ship incineration as a function of tax revenue from improved commercial fishing which may occur in the vicinity of an artificial reef created by residue discharged from an incinerator ship. These values are nominal, and used principally for debugging the model. Other values may be used.

Increased tax revenue ($/ton)	0.10	10.00
Benefit ($/ton)	0.10	10.00

C. Operating Parameters

1. Daily and seasonal variability

In most major Eastern urban areas, solid waste production rates have seasonal variability, e.g., the amount collected is least during winter and an annual maximum occurs in summer. The simulation model incorporates this variability by modifying the baseline daily waste production figure of 1,000 tons/day during the four seasons in each model year. The probability distribution of the seasonal variation adopted for the model is shown in Table 7-2. The model also simulates daily variations in waste generation by randomly changing the daily amounts. The probability distribution of the range of the daily variation in waste generation is shown in Table 7-2 also. The planner can change these numbers in the program so that they correspond with those observed in his own area.

2. Probability functions for weather patterns

Extreme weather conditions can disrupt the waste collection and disposal system for periods ranging from a few hours to days and interruption of the incinerator ship schedule from this cause has been included in the program. The probability of a stormy day which will prohibit safe operations at sea has been determined on a seasonal basis from climatological records of Boston Harbor. Whenever such a stormy day occurs in the model, the waste awaiting shipboard processing is allowed to accumulate in dock or ship storage until the following, or a later, day. The seasonal probability of an excessively stormy day occurring is incorporated into the model and shown in Table 7-3. Since, occasionally, bad weather conditions persist for more than one day, sequential bad days are incorporated into the model, also. Whenever a single bad day occurs, the probability of succeeding days being bad is governed by the relationships shown in Table 7-4, which have been derived for conditions in Boston Harbor. Since additional storage facilities may become necessary for wastes waiting to be disposed of at sea during inclement weather, the program also tabulates the excess storage capacity required, as shown in Function 14.

D. Running the Model

1. Values of the system variables

Full specification of the simulation model requires that values of system variables and descriptive parameters be fixed as shown in Table 7-1.Almost all of these may be changed at the beginning of each model calculation or the program can assign values from a specified range on a random basis.

Whenever a single value of a parameter or variable has been used for all calculations described in this paper, this value is noted; otherwise, only the range of values adopted during the study is indicated.

Random selection of the distribution of waste to final disposal methods, as well as trucking times, was adopted in order that statistical sampling theory might be applied.* After the initial 30 simulation runs (based upon random variable selection), other runs utilizing controlled variation of a few variables (variations of values used during the initial runs) were carried out to demonstrate the capability of the simulation model for sensitivity analysis and decision-making. The results of all analyses appear in Section III.

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*The net benefit can be represented by the equation:

$$B = f(x_1 \ldots x_n)$$

where $x_1 \ldots, x_n$ are chosen at random from the range of possible values and B can be calculated by simulation runs. B is thus a random variable with unknown probability distribution. The probability that the highest value in M runs will be in the upper p percent of the possible run values population is:

$$P = 1 - (1 - p/100)^m.$$

Therefore, if p is 10, a sample size of 20 will include at least one run from the top 10% of the possible runs 95 times out of 100. (P = .957)(2)

2. The simulation output

The model simulates daily waste production and disposition for a 25-year period (1965-1990). The discounted annual costs and benefits, cumulative costs and benefits, and the present value of the total net cost of each combination, operating over a 25-year period, are computed, tabulated, and printed out by the computer. In addition, non-dollar costs and benefits, and considerations such as men and machines required are computed, tabulated, and printed out.

During an initial set of 30 runs, designed to test the utility of the model as an aid to planning decisions for waste disposal systems and to set values for the decision variables marked in Table 7-1. the proportion of total waste disposed of on-site was selected at random by the program within a range of 0-20%. The remaining 80 to 100% of total waste generated (i.e., the collected waste material) was distributed at random by the program among landfill, land incineration, and ship incineration. Assignments remained unchanged during the entire 25-year period unless the landfill limit was reached, which occurred on several runs.

The major elements of printed output from a single 25-year run are reproduced in Table7-5. The values of decision variables actually used by the program in that run, and which change from run to run, are given in Part I of Table V, whereas all other parameters of variables have the values indicated in Table 7-1.

III. RESULTS

A. Model Runs

Thirty model runs were carried out initially to examine relative costs and benefits over a wide range of waste handling and disposal methods. The results are summarized in Table 7-6. Each run was assigned an index number, but the arrangement in Table 7-6 is in order of decreasing present value of total net cost (PVTNC). The following observations are based upon the tabulated results:

1. Twenty-five year PTVNC's varied from approximately $125 million to $190 million and the differences for the various combinations of collection and disposal systems are significant. The distribution of PVTNC's between the two extremes is relatively uniform but slightly skewed to the upper end of the scale. The average PVTNC for the 30 model runs is $159.4 million.

The range of 25-year projected system costs illustrates the importance of informed planning for large scale solid waste management programs. Cost savings by proper system planning can be of the order of many tens of millions of dollars for a major metropolitan system. Although these calculations demonstrate that significant differences in system costs result from the selection of alternative options, more work on individual and combined factor cost analysis is required to delineate adequately system costs and benefits for specific communities.

2. The contribution of various benefit estimates to the PVTNC is small (i.e., less than 1% of the total) in each of the thirty calculations shown in Table 7-6. This results from a decision to limit land filling over the 25-year study period to

20% of the land available at the start and to evaluate the newly-made land at a nominal $1000/acre. In old cities, the amount of land available for filling will be small but, by the same token, the value of each unit of recovered land will be high because of the scarcity. Land values in excess of $1,000,000/acre (3 orders of magnitude greater than assumed for this program) are not unusual for business districts in large metropolitan areas. When land for fill is freely available the value of the recovered land may be lower but there will be substantial savings in waste disposal costs as landfilling is usually far less costly than incineration. Therefore, substantial monetary benefits can accrue to the system when land utilization policies are guided by advance knowledge of how various alternatives will affect the PVTNC over a quarter century. When benefits are about ten percent of the total cost they begin to effect the choice of combinations of disposal methods.

3. Waste management systems which included maximum (up to 20% of the total) use of individual disposal methods (home incinerators, backyard burning) showed lower costs. This was anticipated as the unit cost for individual disposal is lower than for any of the other methods, principally because 80% of total waste handling costs is for collection alone.(3) Nevertheless, examination of Table 7-6 will show that the percentage of individual disposal is not the only system variable (other than collection) that has an important effect on total cost. Nationwide, the system is so costly ($4 billion yearly) that even

minor changes in total cost represent many millions to the taxpayer and, hence, are important.

4. Because sanitary landfilling is the lowest cost final disposal method for collected waste, the model runs which involve heavy land use are generally included among the lowest cost cases. Here, also, other system variables play a significant role as well and the PVTNC ranking shown in Table 7-6 is not exclusively a function of the degree of landfill use.

The land availability constraint for landfilling (1000 acres) was invoked in five of the model runs and, for these, all collected waste was reassigned by the program to land or ship incineration during the final years. In no case was the land available for filling exhausted before year 20 of the 25-year calculation period.

5. As ship incineration costs were set equal to land incineration costs, no cost comparisons between the two methods may be made from the results shown in Table 7-6, but other calculations that involved different estimates of ship costs are described in a later section.

6. In the model, travel time from waste pickup to intermediate storage is more expensive than travel time from intermediate storage via a transfer station to dockside because more men and trucks (per ton of waste) are required for transportation from pickup sites to an intermediate storage site than from intermediate storage to the dock. These costs can be demonstrated to depend upon the size of the trucks and the number of men. This is a de-

cision usually made by planners on some basis other than on the effect the decision will have on total cost or benefit.

7. The probability distribution used in the program to simulate the occurrence of bad weather in Boston harbor resulted in very few days when a ship could not operate safely and bad weather would not markedly affect the costs and benefits of a ship incineration system for this community. Bad weather probability distributions for other areas may easily be substituted in the program for the one used to represent the Boston area.

B. Sensitivity Analyses

To investigate the sensitivity of the net cost of the system to changes in decision variables, supplementary calculations were carried out by varying the landfill constraint, air pollution cost, and ship operating cost. The results affected the ranking of the runs shown in Table 7-7, and thus, by implication, the values of the decision variables as follows:

1. Land use constraint

If unlimited land for filling were available so that no backup land would have to be reserved for periods when incineration was not possible, there would be no need to calculate the effect of the land constraint. Although sanitary landfilling is the least costly disposal method for collected waste, available land is in short supply near many urban areas and it is revealing to document the additional costs which result from a lack of landfill facilities. Therefore, all thirty of the 25-year model calculations described previously were recomputed using 500 (rather than 1000) acres (sufficient to receive 2×10^6 tons of waste) as the maximum availability of all landfill sites but with other system variables unchanged.

Present value of total net costs for all runs in both sets of calculations are compared in Table 7-7. The highest ranked runs were most affected by the more restrictive land constraints as these were the runs which generally involved heavy usage of landfill. Index no. 20 was the least expensive for both levels of land constraints as it employed near-maximum use of individual disposal (as well as short trucking time to intermediate storage and therefore fewer man-hours per ton of waste) and maximum use of available landfill. Several runs (i.e., index no.s 16 [the second ranking choice], 24, 14, 30, 7 and 29) were reduced significantly in relative rank when land available for filling was reduced to 500 acres. With the more severe landfill constraint, costs increased moderately in some cases, but in no case did they decrease.

2. Air pollution control costs

As the need for air use management and air pollution control grows for all urban areas, it is reasonable to expect that operations involving burning of large quantities of waste material will be subject to higher costs for pollution abatement. To show that the model can be used to test the significance of the effects of increased air pollution control costs on total waste disposal costs, the 10 highest ranking (lowest cost) cases shown in Table 7-6 were recomputed after adding two hypothetical additional costs: i.e., \$1.00 per ton above the amounts specified in Function 1 for the air pollution costs attributable to private disposal and \$2.50 per ton above the amounts indicated in Function 9 for land incineration.

Table 7-8 presents comparative results for the 10 highest ranked cases shown in Table 7-6 when air pollution control costs are increased and when there is a tighter land constraint. The average increase due to air pollution cost (when there is 1000 acres of land available) is approximately 6 million dollars over the 25 year model period. When air pollution costs increase by the amounts hypothesized, the relative rankings do not change significantly, demonstrating that a modest increase in abatement cost need not change the decision policy and that changes in land constraints may have a greater effect upon total 25-year costs than changes in air pollution constraints.

3. Decreased cost of ship operation

Projected costs of a large incinerator ship have been variously estimated to be somewhat above and below the cost of land incineration. In the runs shown in Table 7-6, ship incineration costs were set equal to land incineration costs. To consider the effect on rank of lower costs for a ship system, the first ten runs of Table 7-6 were recomputed using a value one-half that of the original ship incineration cost. These new calculations were also used with higher air pollution costs and with both 500 and 1000 acre land constraints. The results of these calculations appear in Table 7-9

The data in columns I and II in Table 7-9 are a comparison of the effect of high and low ship cost on total 25-year PVTNC with all other parameters unchanged. Although total costs are somewhat lower when ship cost decreases, important changes in rank of combinations of disposal methods occur as well. Five of the ten cases made greater use of ship incineration (i.e., index no.s 20, 18, 19, 27, and 2) and the average reduction in the PVTNC was approximately 7 percent.

It may be seen from Table 7-9 that when simultaneous changes in air pollution costs, land availability, and ship costs occur, the PVTNC for various model systems undergoes significant changes. For example, the original conditions of index no. 2 (Table 7-6) resulted in one of the most expensive systems, but when the 500 acre land constraint and higher air pollution costs were postulated, the resulting PVTNC was less than for four other systems. This result emphasizes again the manner in which each of the model parameters determines relative cost. In real systems, the number and range of cost variables can be expected to be as large, or larger, than those cited here. A planner cannot determine intuitively the effect of so many decision variables occurring together but a model can be used to investigate the net result and it can do so before decisions are actually carried out, i.e., while there is still time for change.

IV. CONCLUSIONS

The objectives of this study were to develop and test a decision planning model of an urban solid waste disposal system. In addition to the usual disposal methods of land-based incinerators and sanitary landfills, the model included shipborne incineration and disposal of residues at sea. The system model has been developed as a tool for the evaluation of the results to the community of different combinations of methods of waste disposal on the assumption that many significant aspects of the system can be expressed numerically in terms of cost and benefit functions. The following conclusions are based upon the results of model calculations.

1. The cheapest disposal method, e.g., individual disposal, does not always result in a system having the least net costs because the constraints may impose secondary costs (e.g., air pollution) or prevent the least cost disposal method from being utilized for all of the waste produced. Different combinations of these methods result in significant differences in long-term (25 year) projected costs for waste disposal.

2. Even though the benefit values utilized in the model development (Functions 8, 10, 16) represent only a small percentage of the present value of the total net cost, they cannot be eliminated from the model because they represent nominal values of benefits which must be investigated for a specific community. Benefits amounting to ten percent of the total cost become significant in the choice of combinations of disposal methods. Furthermore, the net cost of waste disposal is so large that a small percent of the total may mean millions of dollars annually to the taxpayer.

3. Reevaluation of the major costs and benefits used in the model is necessary to assure meaningful results when the simulation model is applied to another community. Although it is impossible to project costs exactly over periods of several years, the sensitivity analysis of the model indicates that differential studies can be revealing. When major cost items are

known reasonably well, the scope, cost, and effort of cost-benefit studies can be substantially reduced and the applicability of the calculation markedly increased.

4. The model can be used to examine the effects on the disposal system of decisions which are usually made only on the basis of other considerations; for example, truck size, amount of land available for sanitary fill, percent of land to be available at the end of a specified time period, or air pollution control targets. Estimates of the cost to the community of these operational decisions can become important aids in decision making.

5. Even when accurate costs and benefits of new methods under consideration are not accurately known, estimates can be incorporated into the model, as was done with ship incineration. By changing these estimates and varying or holding constant other variables, the required cost and benefit criteria of the new method can be established. For example, marine engineers can be given these cost and benefit figures and asked if they can design an incinerator ship that will meet them. Alternatively, marine engineers can be asked to estimate the cost of developing an incinerator vessel that meets the required cost and benefit figures. Feasibility studies of any new method can be directed to answer similar questions and the model approach can save a great deal of design time and effort, as well as producing the design budget.

6. The contribution of an incinerator ship to total waste disposal costs and benefits is shown by the model to be significant if the cost of this method is equal to or lower than land incineration.

TABLE 7-1

VARIABLES AND PARAMETERS FOR THE SIMULATION MODEL

		Potential range of values
A1.	Proportion of total waste handled on site by individual disposal methods	0-20%*
A2.	Proportion of collected waste picked up by public organizations	50%*
A3.	Proportion of collected waste picked up by private concerns	50%*
A4.	Proportion of collected waste handled by landfill operation	0-100%*
A5.	Proportion of collected waste handled by land incineration	0-100%*
A6.	Proportion of collected waste handled by ship incineration	0-100%*
A7.	Allowable air pollution index rise, SO_2 units, PPM	1.50
A8.	Land use constraint (percentage of initial landfill capacity which may be used in the 25-year period	20%
A9.	Useful heat production target at land incinerator site	5×10^8 Btu per day
A10.	Tax revenue produced by creation of artificial reefs	$0.10/ton of raw waste
A11.	Capacity of an intermediate storage site	2000 tons
A12.	Capacity of a dockside storage silo	2000 tons
A13.	Location of an intermediate storage site in terms of average travel time from collection units	5-45 minutes *
A14.	Location of dockside storage silo in terms of travel time from intermediate storage site	5-45 minutes *

*Model decision variables

TABLE 7-1, continued

		Potential range of values
B1.	Land available for fill, equivalent tons of raw waste (some fill will be incinerator residue)	2.0-4.0 x 10^6 tons
B2.	Daily capacity of landfill	500 tons
B3.	Value of new land produced by filling	$1000 per acre
B4.	Capacity of a single land based incinerator	1200 tons per day
B5.	Total capacity of three ship based incinerators	1200 tons per day
B6.	Capacity of collection trucks	10 tons
B7.	Men required per collection truck	3
B8.	Waste collection schedule, consecutive hours per day	8 hours
B9.	Capacity of transfer trucks	20 tons
B10.	Men required per transfer truck	2
B11.	Transfer schedule from intermediate storage to dockside storage, consecutive hours per night	4 hours
B12.	Number of truck loading docks at ship	4
B13.	Handling rate for each truck dock	2 tons/minute
B14.	Ship schedule: consecutive hours of loading per day at dockside	6
C1.	Extractable heat from solid waste	2000 Btu/ton
C2.	Oil cost index(no units)	2

TABLE 7-2

SEASONAL AND DAILY VARIATION IN WASTE GENERATION

	Winter	Spring	Summer	Autumn
Seasonal Variation	-.10	+.20	+.25	+.15
Daily Variation	±.02	±.02	±.05	±.02

TABLE 7-3

PROBABILITY OF OCCURRENCE OF AN EXCESSIVELY STORMY DAY

	Winter	Spring	Summer	Autumn
Probability of prohibitive weather	0.030	0.004	0.020	0.004

TABLE 7-4

PROBABILITY OF CONSECUTIVE "BAD DAYS"

Number of consecutive days prohibitive weather after the first	1	2	3	4
Probability of Occurrence	0.75	0.18	0.05	0.02

TABLE 7-5

TYPICAL COMPUTER OUTPUT FROM SIMULATION MODEL EXPERIMENTS

1. **Values Randomly Assigned by the Program**

Proportion of waste by individual disposal	11%
Proportion of waste collected by public and private agencies	89%
Proportion of collected waste by land incineration	19%
Proportion of collected waste by ship incineration	45%
Proportion of collected waste by landfill	36%
Area available for landfill at start of period	2000 acres

2. Computed Results(25 year period)

a. Materials and manpower

Total waste processed, 25 years	$1.263x10^7$ tons
Average waste processed per year	$5.056x10^5$ tons
Average waste processed per day	$1.384x10^3$ tons
Total waste by individual disposal	$1.418x10^6$ tons
Total waste collected	$1.122x10^7$ tons
Total waste to land incineration	$2.130x10^6$ tons
Total waste to ship incineration	$5.047x10^6$ tons
Total waste to landfill	$4.045x10^6$ tons
New land produced at landfill site	1010 acres
Usable heat produced at incinerator	$1.065x10^{10}$ Btu
Artificial reef produced, tons equivalent	$5.047x10^6$ tons
Average number of trucks per day for collection	5.42
Average number of men per day for collection	16.25
Average number of trucks per night for transfer	7.42
Average number of men per night for transfer	14.84
Average number of bad days per year	5.72
Average number of consecutive bad days	1.24

b. Cumulative costs and benefits (present value)

Cost, individual disposal	$\$2.836x10^6$
Cost, all collected waste	$11.351x10^8$
Cost, public collection	$6.754x10^7$
Cost, private collection	$6.754x10^7$
Cost, haul to intermediate storage	$1.277x10^7$
Cost, intermediate storage	$3.509x10^6$
Cost, landfill	$8.211x10^6$
Cost, land incineration	$1.001x10^7$
Cost, haul to dockside	$9.765x10^6$
Cost, dockside storage	$2.020x10^6$
Cost, ship incineration	$2.776x10^7$
Benefit, landfill	$1.011x10^6$
Benefit, land incineration	$1.050x10^6$
Benefit, ship incineration	$5.047x10^5$
Costs, discounted, total	$1.500x10^8$
Benefits,present value, total	$2.565x10^6$
Present value total net cost (PVTNC)	$1.474x10^8$

TABLE 7-6

SUMMARY OF RESULTS FROM ORIGINAL 30 CALCULATIONS

I. A. Rank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
B. Code no.	20	16	13	3	26	19	14	27	[illegible]	[illegible]	[illegible]	23	6	30	28	7	[illegible]	29	11	[illegible]	[illegible]	[illegible]	1	5	4	12	[illegible]	[illegible]	[illegible]	[illegible]
II. (System Variables)																														
a. Prop. of waste collected	.82	.83	.91	.84	.83	.88	.81	.82	.92	.89	.86	.82	.89	.91	.83	.89	.56	.97	.94	.92	.97	.91	.89	.87	.95	.88	.16	1.00	.96	.56
b. Prop. of collected waste to fill	.56	.79*	.60	.26	.95*	.52	.42	.26	.41	.36	.83*	.28	.50	.72*	.28	.29	.07	.75*	.18	.33	.05	.01	.20	.05	.32	.02	.02	.33	.15	.04
c. Prop. of collected waste to incinerator	.08	.17*	.36	.70	.01*	.10	.19	.15	.37	.19	.13*	.52	.35	.05*	.28	.22	.74	.07*	.70	.15	.93	.97	.68	.48	.60	.60	.17	.61	.29	.66
d. Prop. of collected waste to ship	.36	.03*	.04	.04	.04*	.38	.39	.59	.22	.45	.04*	.20	.15	.13*	.44	.49	.19	.19*	.12	.52	.03	.03	.13	.47	.08	.38	.81	.06	.56	.30
e. Travel time to intermediate storage (min)	5	20	5	10	30	5	20	15	15	10	45	35	30	35	35	35	40	40	35	25	25	35	45	40	45	45	30	35	35	30
f. Travel time to dock site (min)	5	45	40	25	40	25	10	10	20	40	25	20	45	[illegible]	45	5	35	15	5	25	25	45	45	35	25	40	45	25	15	10
III. (Results)																														
a. Av. no. of bad days/year	5.60	6.80	6.60	6.36	6.04	6.00	7.16	6.52	7.24	5.72	5.60	6.20	7.32	6.12	6.12	5.64	6.12	6.48	7.48	5.92	6.00	5.88	6.88	6.37	5.96	6.48	6.20	5.60	6.96	6.08
b. Av. no. of consecutive bad days	1.21	1.29	1.30	1.35	1.22	1.34	1.28	1.27	1.28	1.24	1.20	1.25	1.31	1.33	1.29	1.22	1.32	1.29	1.26	1.21	1.26	1.27	1.24	1.31	1.31	1.30	1.29	1.23	1.23	1.40
c. Av. no. trucks for collection	3.0	28.0	3.0	5.1	13.2	3.0	9.1	7.2	8.0	5.4	20.2	16.6	10.2	18.5	16.8	18.0	17.6	19.7	18.5	13.3	13.9	18.0	20.0	17.6	22.4	20.7	11.8	20.2	19.4	21.2
d. Av. no. trucks for transfer	1.1	1.6	1.0	1.0	1.0	1.5	2.2	3.1	2.4	7.4	1.9	2.1	3.6	3.4	8.8	1.8	3.3	1.9	1.0	8.9	1.0	1.0	3.9	7.6	1.5	6.3	16.7	1.9	4.6	2.1
e. Acres of new land produced (X10³)	1.45	2.0	1.73	0.70	2.00	1.43	1.07	0.69	1.19	1.01	2.00	0.73	1.40	2.03	0.74	0.82	0.20	2.00	0.51	0.36	0.15	0.03	0.56	0.13	0.96	0.05	0.05	0.98	0.46	0.12
f. Btu of heat produced (X10⁹)	3.9	9.0	20.7	36.8	1.1	7.7	9.7	7.6	21.5	10.6	7.8	26.4	19.9	7.0	14.5	12.4	40.0	10.3	40.3	8.6	56.6	56.0	37.9	26.1	36.0	33.2	9.2	30.3	17.3	61.2
g. Ton equivalent, artificial reef (X10⁶)	3.7	0.65	0.43	0.43	0.37	3.8	4.8	6.1	2.5	5.4	1.2	2.1	1.7	2.1	4.6	5.4	2.0	2.2	1.3	6.1	0.32	0.16	1.4	5.2	0.97	4.2	8.9	0.99	6.7	[illegible]
h. Present value, all costs (X10⁶)	126.2	131.2	133.4	135.3	136.7	136.9	138.8	143.7	150.1	150.0	153.3	153.8	155.6	160.8	163.6	167.0	166.9	169.3	168.9	170.6	171.3	171.6	172.1	176.5	178.0	179.5	179.7	180.4	185.3	189.0
i. Present value, all benefits (X10⁶)	.389	.677	.710	.309	.665	.461	.251	.088	.492	.309	.708	.238	.544	.724	.162	.234	.130	.797	.311	.306	.110	.016	.292	.023	.523	.047	.137	.586	.181	.210
j. Present value, total net cost (X10⁶)	125.8	130.5	132.7	135.0	136.0	136.4	138.5	143.6	149.6	149.7	152.6	153.5	155.1	160.1	163.4	166.7	166.8	168.5	168.6	170.3	171.2	171.6	171.8	176.4	177.5	179.5	179.6	179.8	185.1	188.8

* Landfill constraint exceeded, redistribution necessary during final years of model calculation.

TABLE 7-7

EFFECT OF LAND CONSTRAINT ON SYSTEM COSTS

	Results with 1000 acres available for land filling.		Results with 500 acres available for land filling.	
Rank in order of increasing PVTNC	Index No. (from Table VI)	PVTNC $(X10^6)$	Index No.* (from Table VI)	PVTNC $(X10^6)$
1	20	125.8	20	129.6
2	16	130.5	3	135.0
3	13	132.7	18	138.9
4	3	135.0	19	139.1
5	24	136.0	13	141.6
6	18	136.4	27	143.6
7	19	138.5	16	145.4
8	27	143.6	24	148.3
9	8	149.6	2	149.8
10	2	149.7	8	152.1
11	14	152.6	23	153.6
12	23	153.6	6	157.7
13	6	155.1	28	163.4
14	30	160.0	14	164.2
15	28	163.4	10	166.8
16	7	166.7	11	168.6
17	10	166.8	25	170.3
18	29	168.5	17	171.2
19	11	168.6	15	171.6
20	25	170.3	9	171.8
21	17	171.2	21	174.4
22	15	171.6	30	176.2
23	9	171.8	7	176.6
24	5	174.4	4	177.5
25	4	177.5	29	179.1
26	12	179.5	12	179.5
27	21	179.6	21	179.6
28	1	179.8	1	179.8
29	26	185.1	26	185.1
30	22	188.8	22	188.8

* Land constraint is the only item changed during re-run.

TABLE 7-8

EFFECT ON TOTAL 25-YEAR COSTS OF INCREASED AIR POLLUTION CONTROL COSTS

Rank in order of increasing PVTNC	Results from Table VI calculated for lower air air pollution control costs.		Results Calculated for Higher Air Pollution Control Costs			
			1000 Acre Land Constraint		500 Acre Land Constraint	
	Index No. (from Table VI)	PVTNC $(X10^6)$	Index No. (from Table VI)	PVTNC $(X10^6)$	Index No. (from Table VI)	PVTNC $(X10^6)$
1	20	125.8	20	129.5	20	135.1
2	16	130.5	16	137.1	19	146.6
3	13	132.7	3	140.5	18	149.1
4	3	135.0	18	141.7	24	149.4
5	24	136.0	24	143.4	27	149.6
6	18	136.4	13	144.0	16	153.5
7	19	138.5	19	145.8	3	155.0
8	27	143.6	27	152.8	13	155.2
9	8	149.6	2	156.4	2	159.5
10	2	149.7	8	161.3	8	162.9

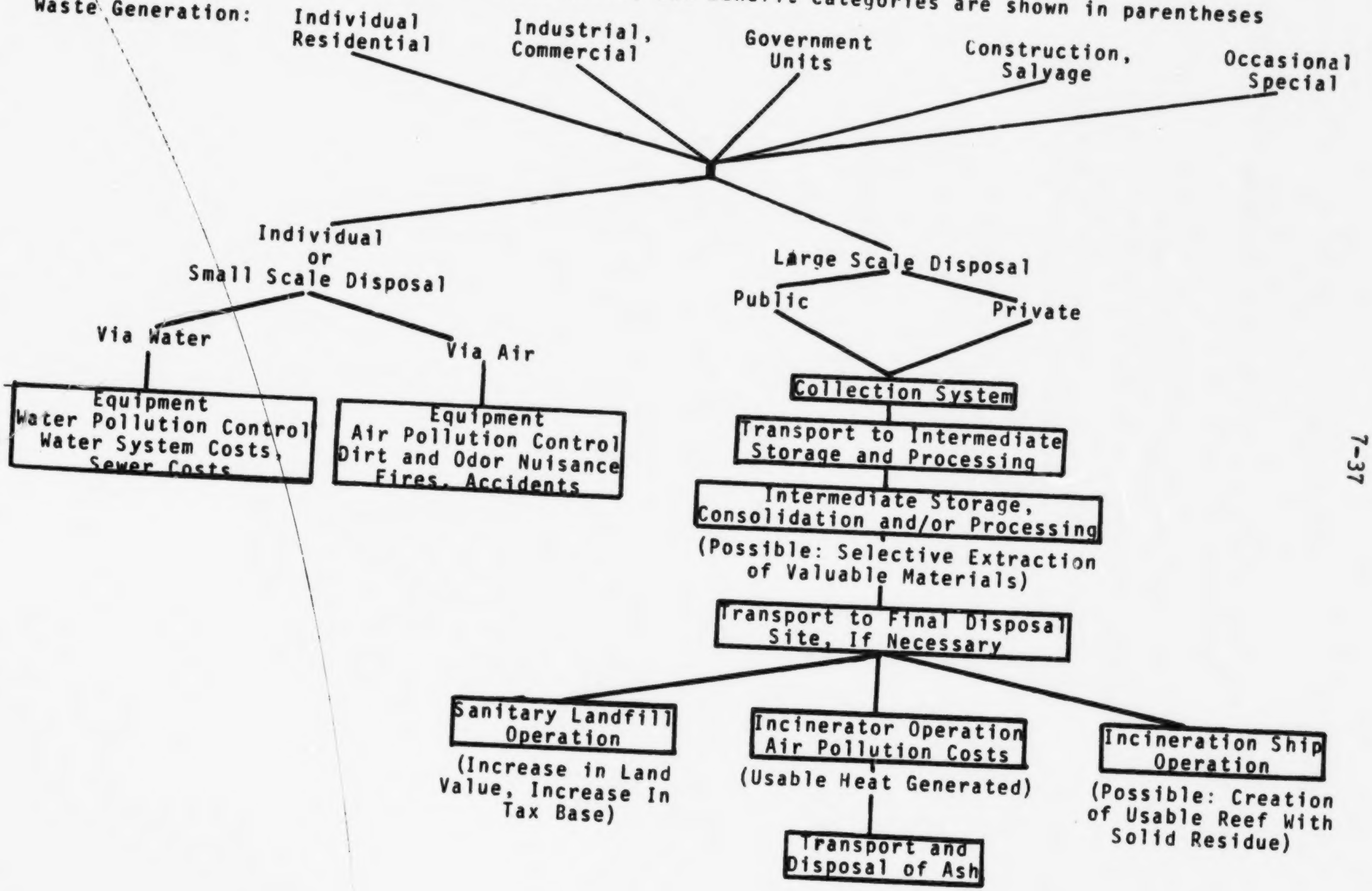
TABLE 7-9

EFFECT OF DECREASED SHIP COSTS ON TOTAL 25-YEAR COSTS

	I		II		III		IV		V	
	Results from Table VIwhich were calculated for high ship costs,low air pollution costs and original 2000 acres of land		Results for Low Ship Costs							
			With Low Air Pollution Costs				With High Air Pollution Costs			
			1000 acres available		500 acres available		1000 acres available		500 acres available	
Rank in order of increasing PVTNC	Index No.	PVTNC (X10^6)	Index No.	PVTNC (X10^6)	Index No.	PVTNC (X10^6)	Index No.	PVTNC (X10^6)	Index No.	PVTNC (X10^6)
1	20	125.8	20	118.4	20	120.8	20	122.1	20	126.3
2	16	130.5	3	127.0	19	131.1	3	132.5	27	137.4
3	13	132.7	18	128.8	27	131.4	18	134.1	19	138.6
4	3	135.0	16	130.2	18	131.7	16	135.9	18	141.9
5	24	136.0	27	130.5	3	134.0	19	138.0	16	145.5
6	18	136.4	19	130.7	13	136.6	27	139.4	2	146.5
7	19	138.5	13	131.9	16	137.4	24	142.7	13	150.2
8	27	143.6	24	135.3	2	139.8	13	143.2	24	153.8
9	8	149.6	2	139.6	24	142.7	2	146.3	3	154.4
10	2	149.7	8	144.0	8	144.9	8	155.7	8	155.7

FIGURE 7-1

SCHEMATIC ILLUSTRATION OF METROPOLITAN SOLID WASTE DISPOSAL METHODS
Cost categories appear inside boxes, and benefit categories are shown in parentheses


Waste Generation:
Individual Residential
Industrial, Commercial
Government Units
Construction, Salvage
Occasional Special
Individual or Small Scale Disposal
Via Water
Equipment Water Pollution Control Water System Costs, Sewer Costs
Via Air
Equipment Air Pollution Control Dirt and Odor Nuisance Fires, Accidents
Large Scale Disposal
Public
Private
Collection System
Transport to Intermediate Storage and Processing
Intermediate Storage, Consolidation and/or Processing
(Possible: Selective Extraction of Valuable Materials)
Transport to Final Disposal Site, If Necessary
Sanitary Landfill Operation
(Increase in Land Value, Increase In Tax Base)
Incinerator Operation Air Pollution Costs
(Usable Heat Generated)
Transport and Disposal of Ash
Incineration Ship Operation
(Possible: Creation of Usable Reef With Solid Residue)

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